

## **The Nymophone2.**

– a study of a new multidimensionally controllable musical instrument

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Master's Thesis

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## Preface

In this thesis I present a two-part Master's Project. The first part of this project is the practical development of the Nymophone2, a new musical instrument, and the second part of the project is this thesis where I will document and present a theoretical evaluation of the Nymophone2.

After working on this thesis for two years, investigating theoretical and practical issues of perception, musical instruments, sound analysis and musical movement, I have more questions than what I started with. This thesis is an attempt to understand another small piece of the many mysteries of music, even though I never will get the whole picture.

First of all I would like to thank my supervisor, prof. Rolf Inge Godøy, for inspiration and support, for presenting me with relevant theory and questions when I have been stuck. Thanks also for allowing me to participate on the Musical Gestures and Sensing Music-related Actions projects at the University of Oslo. I am deeply grateful.

I would also like to thank Alexander Refsum Jensenius for several conversations on topics related to music technology and music-related movement, and for introducing me to music technology research communities outside of our research group.

Thanks to Ole Kristian Sakseid for presenting ideas during the construction of the instrument, for helping out with the practical experiments and for being willing to learn to play the Nymophone2.

Thanks to Tor Halmrast and Tellef Kvifte for supervising courses in digital signal processing and organology and for giving valuable feedback during the past two years. Thanks to Erik Nilsen, Søren Holme Hansen, Joseph Malloch, Stephen Sinclair and Alicja Knast for discussions on music cognition, technology and suggestions on practical and theoretical aspects of my Master's project. And thanks to Ida E. J. Aasebø for proof-reading the thesis.

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Kristian Nymoen

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## Chapter 1: Introduction

In this thesis, I present the *Nymophone2*. The name was chosen as a follow-up to the musical instrument *Nymophone*, which I made for a semester assignment in a course on sound theory a couple of years ago. The two instruments are quite different in many aspects, but I still see them as a small family of odd (in the best possible meaning of the word) musical instruments which hopefully will grow into a larger family providing new possibilities for musical expression.

The first Nymophone, or the *Nymophone1* as it is now called, is based on a hacksaw blade, freely vibrating in one end, and in the other end clamped between two ball bearings. The blade can be drawn back and forth between the ball bearings to adjust the freely vibrating length of the blade, and thereby adjusting the pitch. The blade is put into motion with a bow or by plucking it, and the vibrations are amplified through an electronic system similar to that of an electric guitar.

In short, the Nymophone2 is a musical instrument with four strings attached to a stressed, flexible steel plate. By *stressed* I mean that the strings are tightened, bending the plate into a curved shape, when the “natural” state of the plate is a flat surface with no curves. The plate is attached to a wooden frame, and two electromagnetic pickups pick up the vibrations of the plate and the strings. The instrument is connected to an amplifier and, if desired by the performer, modules for sound modification.

My initial thought was to create a musical instrument which would expand the sonic universe from what was available before the instrument was created. I wanted this instrument to have a certain appeal to my own musical and aesthetic preferences. It should be a physical instrument, where the sound production was based on some kind of physical vibrations, rather than digital signal processing. The reason for this is mostly a subjective preference, but also a result of wanting to give a slightly different perspective than other research on development of new musical interfaces, which currently has a main focus on digital musical instruments.

In most traditional musical instruments, there are clear distinctions between the main roles of the different parts of the instrument. These distinctions have been the basis of systems for instrument classification since the first well-documented system for instrument classification by Victor Mahillon (Kvifte 1989: 11). For many years, it has been customary to classify the instruments according to the *primary vibrating material*, like for instance *chordophones*, where strings are the primary vibrating material.<sup>1</sup> Further on, there are usually clear distinctions between what parts of the instrument that are *control organs* (like the keys and pedals of a grand piano) and the parts that are passive sound modifiers (like the soundboard of a grand piano). The distinctions between differ-

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<sup>1</sup> This is part of a much larger field of systems for instrument classification. This is further addressed in chapter 2.

ent parts of the instrument has become less prominent with the rise of new music technology in the 20<sup>th</sup> century, especially with the development of new digital musical instruments where the primary vibrating material and any passive sound modifiers are more abstract. In these instruments the control mappings may be too complex to distinguish between the primary vibrating material (or oscillator) and the rest of the instrument.<sup>2</sup> In traditional musical instruments, the performer may usually control a musical feature in a limited number of ways. For instance, on a recorder, pitch is controlled by the finger positions and the wind pressure. Research have shown that complexity in control of instruments is part of what makes an instrument interesting to interact with (Hunt et al. 2002). I find such complexity interesting, and thus my main goal for this thesis is to evaluate the use of a more complex, and multidimensionally controllable system for musical expression. In the Nymophone2, the primary vibrating materials of the instrument are not only elements whose resonances are causing sonic vibrations; the same elements are also the most significant control input for the performer, and the bearing construction of the instrument.

In Chapter 2 I will present the theoretical background on which I shall discuss the Nymophone2 in later chapters. I have separated this chapter into a section on historical background and a section on current research. Where the section on current research contains presentation of recent and ongoing work on the topics that are relevant to this thesis, and the section on historical background presents some of the theoretical background for current research on music technology and music cognition.

In chapter 3 I shall present a short version of some of the development process, from before the idea to the final instrument. I had many aspects to consider simultaneously, so it would be impossible to give a complete account of the first process, but I will include the main events that led to the final instrument. The final version of the Nymophone2 is presented in detail, and this chapter is the documentation of the practical part of my Master's project.

Before going into the analytical sections, I shall give an overview of the analytical tools I have used in this process. It is necessary to mention that all the plots displayed in print are of poorer resolution than what may be extracted from within the analysis software. I have been using software-implemented algorithms for reading values of the plots. I mention this in case the reader would question how I could get very accurate data from the low-resolution plots that are printed here.

During the process of working on this thesis, I have gradually developed a goal of linking my work to state of the art music cognition research.. As I myself have been working on development of methods for gathering and processing music-related movement data (Nymoen 2008), I

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2 Like for instance a synthesizer using a feedback loop from the output sound to modify the signal from the oscillator.

believe that this research is relevant to other music research as well. Chapter 4 presents recordings of performances on the instrument, with the purpose of illustrating playing technique in light of current music technology development. By this I hope to point out strengths and weaknesses of this technology.

In chapter 5 I will discuss the findings of the three previous chapters. I will apply theory of musical instrument classification presented in chapter 2 to the physical construction of the instrument. I shall also present a more complete description of playing technique than what is presented from the experiment in chapter 4, based on the theory presented in chapter 2 and the recordings from chapter 4. Finally, I will look at cognitive aspects of this musical instrument, related to psychoacoustics and complexity in instrument control.

Some remarks need to be made initially regarding terminology used in the thesis. In the theory presented, different terms have been used to refer to a single phenomenon. This is both due to different translations of the original texts and use of different terms in different publications for the purpose of specifying the meaning of the term. As an example, the term *sound variables* (Kvifte 1989) has in later publications been changed to *musical parameters* (Kvifte and Jensenius 2006). The two terms describe the same thing; Kvifte (1989) uses *sound variables* to describe sound from an instrument, and writes that the sound from an instrument must be understood as *music* (ibid: 62). Thus, *musical parameters* is used to indicate that the parameters apply to music, but not necessarily to the acoustic phenomenon *sound*. I do not devote much room for discussion of differences in terminology at this point, but use footnotes where I find it necessary to compare or explain the use of one term instead of another.

When I talk about the action of shortening a string, I mean the act of using an object to touch the string, so that the vibrating part of the string is shorter. The word “fretting” is sometimes used for this in regard of guitars, but as the Nymphone2 does not have frets the term would not be appropriate. Another used term is “stopping” the string, but I find it likely that this term could be confused with damping the vibrations of the string.

I would also like to remark that I support the view presented by Jensenius (2007b) that the term *gesture* is problematic, thus I will generally use the words *action* and *movement*, and the term *gesture* only in the context of referring to theory in which the term is used. I will address terminology of movement research further in chapter 2.

I have chosen not to present any theoretical background for physics-related concepts such as acoustics and electronics, although I use terms from these fields in this thesis. Most of the physics-related aspects used here are of such an elementary nature that I have chosen not to devote space for it in this chapter. However, I will give brief explanations when I use physics-related terms and the-

ory that I find necessary to explain.

Pictures, sound and video examples are included on the CD-ROM found on the back cover. The sound files referred to in the figures are found in a separate folder, with file names referring to the figure numbers. An overview of the CD-ROM contents is found in Appendix B. Additional information including pictures and sound files of Nymophone1 and Nymophone2 is available from: <http://folk.uio.no/krisny/nymophone>

## **1.1 Initial considerations on multidimensionality**

Because the subtitle of this thesis is “a study of a new multidimensionally controllable musical instrument” I would like to introduce some thoughts on multidimensionality already at this point. The term *dimension* is in the *Compact Oxford English Dictionary of Current English*<sup>3</sup> defined as either “a measurable extent, such as length, breadth or height” or “an aspect or feature”. The latter understanding of the term denotes in this thesis dimensions as features of sound, as features of actions used for controlling an instrument, and as features of the *mappings*<sup>4</sup> between these; for instance, a perceptual feature, i.e. dimension, of sound is *loudness*. A sound will be perceived as louder, equally loud or softer than another sound, hence the hierarchy of perceived loudness is *one-dimensional* in terms of the first definition of dimensionality presented above. However, as a perceptual phenomenon we do not perceive loudness only in terms of one the physical parameter, but due to the attributes of our hearing system several other aspects influence the perceived loudness (Mathews 1999). Thus, following the second definition of dimensionality presented above, we can say that loudness is a *multidimensional* concept in the sense that several physical aspects must be outlined to define the perceived loudness. Other aspects of sound perception and dimensionality are discussed in the next chapter. In the context of mapping *control features* to *musical features*, multidimensionality may appear in three main categories. In mapping theory the main categories for multidimensionality are usually called *one-to-many*, *many-to-one*, and *many-to-many* mappings (Hunt et al. 2000). For instance, a many-to-one mapping means that an output feature is not defined by one input feature alone, several features of the input must be distinguished to define the output. Most, if not all, musical instruments are multidimensionally controllable. However, I will demonstrate that the complexity related to controlling the Nymophone2 is, compared to most instruments, extreme, and through different perspectives evaluate the use of such a complex instrument for music.

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3 [http://www.askoxford.com/concise\\_oed/dimension?view=uk](http://www.askoxford.com/concise_oed/dimension?view=uk) [accessed on 22.04.2008]

4 Mapping means “in which way input features controls output features”, which for a musical instrument means features of the control actions as input features and sound features as output features.

## Chapter 2: Theory

In this chapter I present the theoretical background for this thesis. The main theories that I will refer to in the evaluation of different aspects of the Nymophone2 in later chapters are presented here. I will start with a historical background including theory of cognitive processing of auditory input, and theory of instrument description, classification and playing technique. These aspects are relevant to the evaluation and the documentation of the Nymophone2, and for understanding the structure of musical instruments in general.

After the presentation of historical background I will present some of the more recent and current research that is founded on the presented theories. I will focus on different aspects of music-related movement, a field which is relevant to both music perception and performance, and thus an important aspect of development of musical instruments and study of playing technique.

### 2.1 Historical Background

#### *Interpretation of auditory input*

To a performer interacting with a musical instrument, feedback from the instrument is important. Such feedback is often multi-modal, but in all musical instruments the auditory feedback stands in a special position. As I will present in this chapter, the auditory feedback can not be described in physical terms alone. Cognitive processing and interpretation is an important part of perception. As a point of departure for this discussion, I will here present an overview of Pierre Schaeffer's phenomenological theory on sound perception, and outline a few other theories that relate to Schaeffer's thoughts.

Pierre Schaeffer presented in the 1960s a theory of perceived sound as consisting of *sonic objects* (Schaeffer 1998). The theory was founded on experience from using sound recordings on phonograph and electromagnetic tape, and cutting and adding together pieces of the recordings. Using his experience as basis, he pointed out curiosities in human perception of sound. He argued that the traditional way of reading music from a score does not by itself provide a good enough picture of the sound in question; in particular the information on timbre is not adequately presented in the score (ibid: 15). The sonic objects are perceptual units of sound on which we can focus our attention through what Schaeffer calls *reduced listening*.<sup>5</sup> This reduced listening is concerned with disregarding the everyday connotations of sound, and focusing on different features to gradually learn more about the sonic object in question (Godøy 2006b). According to Schaeffer (1998: 59),

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<sup>5</sup> In the English translation of (Schaeffer 1998), *reduced hearing* is used for Schaeffer's term *écoute réduite*. Godøy (2006b) uses the term *reduced listening*, which is a better term if it is to be interpreted as presented in the text.



the sonic object is defined by its *causal coherence*, i.e. a logical relationship between the sound and a cause. The sonic object manifests itself as a discrete unit, as opposed to the continuous auditory stream. The division between these units is done at discontinuous points in the auditory stream, a principle Schaeffer calls *stress-articulation* (ibid: 67). Godøy (2006b) emphasises the importance of this principle. He connects Schaeffer's principle of stress-articulation to the phenomenon of *chunking* sensory streams.

The phenomenon of *chunking* is a fundamental concept in phenomenology and cognitive theory. Theories on the phenomenon can be found in the 19<sup>th</sup> century in the works of Edmund Husserl (Godøy 2008). The theory claims that we do not perceive sensory information as continuous streams, but as discontinuous “now-points”, where each now-point consists of an awareness of the current moment as well as of the immediate past and expectations for the nearest future. As an example Husserl mentions a melody, which only appears as a unit when each tone is compared with the previous tones and expectations for the further progression of the melody (ibid).

Schaeffer introduces three different types of sound execution which are directly linked to one of the following types of sound-producing actions; *impulse*<sup>6</sup>, *sustained* and *iterative* (Schaeffer 1998). Sonic objects classified as impulsive are decaying after a short ballistic attack, the *sustained* category denotes objects that have a constant flow of energy, where excitation is continuous, and the *iterative* category is a hybrid between the first two categories; a continuous stream of discontinuous attacks. These types of sound excitation emerge as features of the auditory stream, and thus may trigger chunking (Godøy 2008). Schaeffer also introduces three types of what he calls *tonal mass*. A sonic object that is perceived as having a distinct pitch is a *tonal* type, an object of no clear pitch is an object of *complex mass*, and an object of varying pitch is an object of *varied mass*.

Schaeffer points out that this typology for sonic objects is not absolute. An object may have properties of several types at the same time, and may be classified differently according to the perspective of the listener (Schaeffer 1998: 75). This is also found in the phenomenon of chunking, where perceptual streams can be arranged to chunks of different sizes according to the focus of the perceiver. Schaeffer's idea of auditory inputs being subject to division by cognitive processing has later been verified in research on auditory perception, like the work by Albert Bregman (Bregman 1990), (Bregman and Ahad 1995).

Albert Bregman (Bregman 1990) presented several implications of cognitive processing of auditory information. Exploring auditory input in light of the gestalt principles, he demonstrates that

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6 Again, the English translation of Schaeffer (1998) uses a term that not completely fits with the original text. Schaeffer's French term is *facture du type impulsion*, which has been translated to *execution [...] of the pulse type*. Once again I use Godøy's translation, *impulse*, because I find this term more appropriate to describe a type of sound execution.

the process of chunking auditory information depends on the context of the information. The gestalt principles seem to provide a good framework for understanding how auditory information is chunked in different situations. For example (Bregman and Ahad 1995: audio CD track 16) present a short sequence of four short tones, where the first and last tone are of the same frequency and the middle tones are of higher, different frequencies. Presented alone, the four-tone sequence is perceived as one chunk of auditory information, but by prefixing and appending tones of the same frequency as the first and last tone of the sequence, the two middle tones are released from the four-tone sequence and perceived as a separate chunk.

The cognitive aspects of sound perception presented above are important to human interaction with musical instruments. Sound typologies and chunking are important aspects of the feedback to the performer. Before discussing how this theory relates to human interaction with musical instruments, it is necessary to discuss theory on musical instruments and instrument control.

### *Classification and description of musical instruments*

An important part of the theory of musical instruments is the theory on how to classify and describe the instruments. This academic branch of musicology, called organology, originates in the work of Victor Mahillon (Kvifte 1989:10f). Mahillon's system for instrument description and classification divided musical instruments into four branches; the *autophones* (percussion instruments), *instruments à membranes* (instruments with membranes), *instruments à vent* (hollow instruments or wind instruments) and *instruments à cordes* (string instruments).

Curt Sachs (1942) gives credit to Mahillon for laying the foundation for a logical classification system for musical instruments. Erich M. von Hornbostel and Curt Sachs collaborated on a revision of the Mahillon system. Since its publication the Hornbostel/Sachs (H/S) system has been one of the most important, and perhaps the most widely used system for modern instrument classification (Kvifte 1989:17). The H/S system is divided into five classes: The first class, *idiophones*, are instruments that are “made of naturally sonorous materials not needing any additional tension” (Sachs 1942: 455). Idiophones are further divided into lower categories by the way one excites them, e.g. by stamping, shaking, striking, etc. (ibid: 455f). The second class in the H/S system is *aerophones*, which include instruments with a tube enclosing a column of air which is put into vibrations and “free aerophones” which cause vibrations in non-enclosed air. Aerophones are divided into sub-categories by the element which is used to put the air into motion, e.g. reed, lips, etc. (ibid: 457ff). Hornbostel/Sachs' third class are the *membranophones*. These use any kind of membrane as the primary vibrating material stretched over an opening, and are further distinguished and described according to the instrument's construction parameters (like the number of drum

heads, the shape of the drum, etc. (ibid: 459ff). *Chordophones* is the fourth H/S instrument class, these instruments base the sound generation on string vibrations. Similarly to membranophones, they are described in terms of constructional parameters (ibid: 463ff). The fifth instrument class is *electrophones*, which is divided into electromechanic and radioelectric instruments (ibid: 467), in addition to a seemingly unnamed<sup>7</sup> category: instruments where an “electric action [take] the place of a former mechanical or pneumatic action” (ibid: 447). In electromechanic instruments a mechanical vibration is electrically amplified, and in radioelectric instruments an electric circuit oscillates as a basis for sound production (ibid).

The instrument subclasses in the H/S system are further differentiated on class-specific criteria. Each main class and all subordinate levels are given a numerical identifier. These numbers together make up a decimal system which makes it possible to identify any instrument by a number. For instance, the class *idiophones* on the top level has the number 1. As mentioned, idiophones are subsequently categorized according to the method of excitation; e.g. plucking which has the number 2. This means that the first part of the numerical identifier for a plucked idiophone is 12 (Kvifte 1989: 20).

Herbert Heyde presented what he called a *natural system* for instrument classification (Heyde 1975). This work has unfortunately not been translated from German (which I do not read very well). When I cite his work, I therefore use Kvifte's (1989) work as a reference in addition to the original text. Kvifte presents a summary of Heyde's system for instrument classification where the presentation of the system is clearly distinguished from Kvifte's evaluation of it. I trust the presentation by Kvifte to be a correct interpretation of Heyde's work, and use his translations from German to English when referring to Heyde's terms. In this presentation I emphasise the aspects of this system that are the most relevant for application to the Nymphone2.

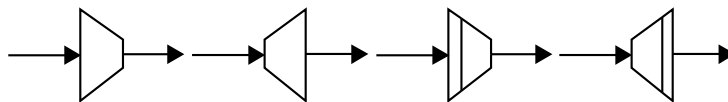
Heyde's system contains four classes; the *system class*, the *formal class*, the *category class* and the *dimension class* (Kvifte 1989: 45f). The different classes allow instrument descriptions to be done in more or less detail. By considering the top class, i.e. the *system class*, it is possible to separate different types of instruments from each other. This class includes the different *functions* that the various parts in an instrument may have. Describing instruments in terms of the *formal class* allows one to draw distinctions between different types of *system class* elements. In Heyde's opinion the instrument is not constrained to be separate from the human body, but the *function elements* described in the system class may be both *anthropomorph*, which means a human element, and *technomorph*, meaning a technological instrument element (ibid: 58). The *category* and *dimension*

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<sup>7</sup> Sachs (1942: 547) mentions this as a subclass of electrical instruments, but for (to me) unknown reasons he chooses not to name this class.

*classes* describe the different shapes and sizes that the different elements of the system class may have.

Heyde assigns a symbol to each of the different *function elements* in the *system class*. Together these symbols make up a diagram describing the instrument in question. Some of the symbols are unique to the element type (like the transformer shown in figure 1). The square symbol (like the shown for the intermediary, the intermediary transformer and the modulator in figure 2 on



**Figure 1:** The four mecano-acoustical transformers in Heyde's system class. From left to right: passive transitive, active transitive, passive intransitive, active intransitive.

the next page) is shared between several element types. Heyde uses letters referring to the German element name to separate these symbols. To avoid confusion, I do not use letter abbreviations, but write the full name of the element when necessary.

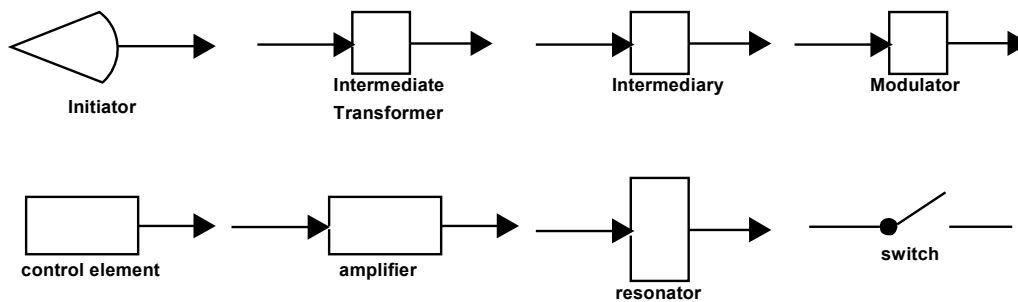
The function element *transformer* has the role of transforming energy from the surroundings or from the performer into vibrations that directly or indirectly becomes the sound from the instrument.<sup>8</sup> Transformers are divided according to what sort of energy conversion they perform, e.g. *electro-mechanical* or *mechano-acoustical*. The mechano-acoustical transformers are further separated according to whether they vibrate themselves (transitive) or if they cause other objects to vibrate (intransitive) without vibrating themselves, and whether they are stationary (passive) or moving (active). The symbols for these mechano-acoustical transformers are displayed in figure 1.

An *initiator* is an element supplying the necessary energy to the transformer. The two are not necessarily directly connected, but may use an *intermediary* to adapt the energy from the initiator to the type needed by the transformer. An *intermediate transformer* is an element that transforms acoustical or optical vibrations into electrical vibrations, a *modulator* is an element that alters an electrical representation of a tone, and an *amplifier* is an amplifier and a loudspeaker for transforming electrical vibrations into sound<sup>9</sup> (Heyde 1975: 46f). The amplifier has a mechanical equivalent in the *resonator*. The function of a resonator may be both amplification and timbre modification (ibid: 47). A *switch* is an element routing the energy; either by stopping the energy flow (direct switch) or by changing the energy path (indirect switch) (ibid: 55). A *control element* controls other elements, either directly or through a *setting element*. This control is either *switch control* – con-

8 Kvfite writes: "The transformer transforms the energy [...] into sound. The sound may be heard immediately, or it may have to pass through some further elements (e.g., an amplifier) to be heard." (Kvfite 1989: 46). I have chosen to use the word *vibrations* rather than *sound*, as I find sound in a musical context to be only sound audible to humans, whereas vibrations may involve both sound, electricity and structural vibrations within an instrument.

9 Heyde's German terms are complicated to translate directly into English. I use Kvfite's translations where both of Heyde's terms *Amplifikator* (denoting the function element) and *Verstärker* (denoting an audio amplifier or signal booster) are translated to the English word *Amplifier* (Kvfite 1989: 47), (Heyde 1975: 47).

trolling switch elements, *energy amount control* – controlling continuous energy variables, or *energy state control* – controlling discrete energy variables (ibid: 55f). Figure 2 presents several of Heyde's symbols.



**Figure 2:** Other symbols in Heyde's system for instrument classification

Heyde also separates between *nervalen Steuerung* and *Programmesteuerung* for the control functions. The *nervalen Steuerung* are control functions related to the human central nervous system and are the control functions for muscles etc., and the *Programmesteuerung* functions are technological control functions, which often are simulations of the *nervalen Steuerung* (Heyde 1975: 49f).

### Playing technique as classification

Tellef Kvifte (1989) presents a detailed overview of the most prominent systems for instrument classification, and presents several problems related to using technical features of an instrument as a basis for instrument classification. Kvifte proposes a new way of classifying and describing musical instruments founded on playing technique. In the following section I present this system and the terminology used by Kvifte. I will refer to Kvifte's system and terminology in the following chapters when I look into playing technique for the Nymphone2.

Controlling the sound from an instrument may be described in terms of *control variables*. The control variables are a combination of the parts of the instrument which are responsive to control, called *control organs*, and the actions the performer may do during the performance, called *control actions* (Kvifte 1989: 63ff). Kvifte does not limit the control actions to only include the actions that directly influence the sound. Using the example of a percussionist playing mute strokes in the air, he writes: “Even if the mute strokes do not directly result in sound, they are clearly a part of the playing technique” (ibid: 65). Kvifte emphasises the need to describe playing technique from the performer's perspective, and thus he uses perceptual rather than physical parameters, e.g. *pitch* rather than *frequency*.

Kvifte's term *sound variables* denotes features in the musical sound that can be controlled by

a performer.<sup>10</sup> At the most general level of description these variables are *pitch*, *loudness*, *timbre*,<sup>11</sup> and *duration*. There is a fundamental difference between the sound variables in terms of how a human being can distinguish between variations of a sound variable (Kvifte 1989: 72f). Kvifte calls this different *levels of measurement*. The sound variable timbre is at the lowest level of measurement, called the *nominal level*. For instance it is not hard to separate the sound of a trumpet from the sound of a violin because of different timbre, but one can not make an objective hierarchy of timbre. It is possible to make subjective evaluations of aspects of timbre, like graininess (e.g. a bowed double bass sound is more grainy than a piccolo flute), but not an objective, one-dimensional hierarchy.<sup>12</sup> The sound variable loudness is at the next level of measurement, called the *ordinal level*. One can compare and order loudness, telling if a sound is softer or louder than another one, but from a perceptual perspective it is problematic to make quantitative comparisons. The *interval level* has ordered systems where one can compare the interval between two instances to the interval between two other instances. The sound variable pitch is at this level of measurement as one can compare the interval between two tones, e.g. the interval between C' and G' equals the interval between A' and E'. From a musical-perceptual view, it is not meaningful to compare pitch in terms of absolute ratios, e.g. which tone is twice as high in pitch as a C'? and there is no meaningful “zero pitch”. The highest level of measurement is the *ratio level*, where one can quantitatively compare two intervals. Duration is the sound variable at this level; for instance, it is meaningful to talk about a note lasting four times as long as another note, and Kvifte also claims that it is meaningful to talk about an experienced zero-point.<sup>13</sup>

In addition to the levels of measurement presented above, the variables can be described as either *continuous* or *discrete* (ibid: 73).<sup>14</sup> A continuous variable is a variable that has an infinite resolution. For example, the force used to hit a piano key is a continuous variable. A discrete variable is divided into separate predefined values, e.g. the choice of which piano key to hit.

When making an overview of types of control actions, Kvifte uses the term *types of movement*. He presents examples of types of movement, such as *static force*, *dynamic force*, *position*, *choice* and *form* (ibid: 107ff). I believe it is more reasonable to divide these types of movement into

10 (Kvifte and Jensenius 2006) use the term *musical parameters* in stead of *sound variables*. I will use *sound variables* only in reference to (Kvifte 1989).

11 Kvifte actually uses the term *tone color*, but has in later publications [i.e. (Kvifte and Jensenius 2006)] used the term *timbre*. I use timbre consequently to avoid any confusion.

12 Experiments on a multidimensional hierarchical organization of timbre has been carried out by D. L. Wessel (Wessel 1979). I will outline some of the basics for this system in the section on psycho-acoustic evaluation of the Nymphophone2 in chapter 5.

13 I find the use of the sound variable duration to be problematic when describing playing technique. Zero duration would necessarily also mean zero loudness, and short durations also influences the other sound variables like pitch and timbre (Schaeffer 1998: 29ff). Kvifte (1989: 89) points out that this sound variable stands out compared to the other sound variables, but does not address this problem any further.

14 In Kvifte (1989), the terms *analog* and *digital* are used in stead of *continuous* and *discrete*.

parameters concerning static positions (which in (Cadoz and Wanderley 2000) are called *postures*) and parameters concerning actions. The latter is done in (Kvifte and Jensenius 2006), where the term *gestural parameters*<sup>15</sup> is used to distinguish features of the movement from technical features of the instrument. Control variables relating to postures could be described in terms of *posture parameters*. For a wind instrument, the posture of the mouth cavity could be described in terms of the parameter form.

Each of the sound variables can be controlled by several control variables, and each control variable can control several sound variables. In Kvifte's system, these multidimensional mappings between sound and control are denoted *sound variable couplings* when one control action influences several sound variables, and *control couplings* to when one sound variable is depending on several control actions. He presents a system for a schematic description of playing technique for instruments including these couplings. He emphasises that the visualizations are not meant as a complete descriptions (Kvifte 1989: 89). They do however provide an overview of the most important aspects of playing technique of the instruments. An example of playing technique for a willow flute is shown in figure 3 where there is a sound variable coupling in discrete pitch, and a control coupling in wind pressure.

	pitch		loudness		timbre		
	C	D	C	D	C	D	
Opening/Closing hole		<input type="checkbox"/>					
Wind Pressure	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>				<input type="checkbox"/>
		<input type="checkbox"/>					

**Figure 3:** Kvifte's diagram for playing technique on a willow flute. C and D means continuous and discrete. The right column denotes sound variable couplings, and the bottom row denotes control couplings. After (Kvifte 1989: 106)

Kvifte's next aspect regarding playing technique description, is the question of to what extent a performer can control the features of a tone. He uses the term *domain* to denote which values that can be achieved for a certain variable under given circumstances. An ordered domain is defined by its *range*, which denotes the outer extremes of the domain, and its *resolution* which denotes the different values that can be achieved within the range. For instance the *pitch domain* of an electric guitar with traditional tuning, without taking into account playing techniques like flageolets and pulling the strings, is approximately within the range of E in the great octave to a three-lined E, and the resolution is at semitones. It is also possible to talk about the domain of a certain control action or a control organ. For instance on a guitar, the control action of pulling a string to increase pitch would typically have an unlimited resolution and a range of about a major third;

<sup>15</sup> I prefer using the term *action parameters* due to different use of the term *gesture* as pointed out in (Jensenius 2007b)

this range however, is dependent on where on the guitar neck the string is being pulled. This is the phenomenon of *multi-level domains*. In the example of pulling a guitar string, the choice of position along the neck would define the domain of the “pulling string” action. If the left hand position is high up on the neck, the range is larger than if the left hand position was way down on the neck. Kvifte (1989: 119) denotes the left hand position along the guitar neck as a domain-selector for pitch. In addition to this, it is a domain selector for other control variables like the range of the pulling-string action, and a domain selector for timbre (an E' sounds different in the 24<sup>th</sup> fret on the lowest E string and as an open E in the brightest string).

Another aspect of sound variable control is to what extent one may control a sound variable after the initial attack. Kvifte presents an overview of which sound variables of a tone that can be controlled after the initial attack for a selection of instruments (ibid.: 113). In my understanding this table is really an overview of which sound parameters that can be controlled in other ways than what can be called a decaying envelope. By decaying envelope I mean that a given sound variable can be controlled, but it can not be restored to a perceptually equal value after the initial adjustment.<sup>16</sup> In Kvifte's overview, the instruments with decaying tones have one or no degrees of control over the tone after the attack. Instruments with sustained excitations have greater control of the sound after the initial attack. These instruments have up to three degrees of control. The performer may control pitch, loudness and timbre after the initial excitation.

I will refer to terms from Kvifte's system frequently in the following chapters. The system provides a good framework for describing playing technique. I will return to some of Kvifte's recent research in the next section, upon discussing technology and systems for instrument description in regard of music-related movement.

## **2.2 Current Research**

The theoretical overview presented above has led to research in embodied music cognition, musical instrument design, human-computer interaction in musical contexts among other things. I will present some of the current research in music technology and music cognition that is relevant to the work presented in this thesis. The theory I will present in this section is still work in progress, and thus there is not a common consensus on the definition of all the terms in use, as I shall discuss in the following sections.

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16 For example, Kvifte writes that the only control possibility of a guitar tone after the attack is the control of the musical parameter *pitch* (which may be controlled for instance by pulling the string with a finger on the left hand). The sound parameter being controlled does in this case not have a decaying envelope, as it may be adjusted back to the initial value by letting go of the pulling tension on the string. For the same instrument, a sound parameter with a decaying envelope would be the result of the action of softly damping the strings very close to the bridge. In this way, both timbre and loudness may be adjusted after the initial attack, but without a new attack the adjustment of these sound variables cannot be reversed.



## *Embodied music cognition*

Within the field of music research, music-related movement has become one of the major research topics over the last decade. This field is concerned with the way performers, dancers and other perceivers of music move in relationship to music, and has also become an important aspect for describing musical instruments. Movements in musical contexts have been described with a large variety of terms, where most of the terms are related to playing technique and performance. In my opinion, a good starting point for a discussion of classification of movements, distinguishing between different types of movement, is done in the terminology of François Delalande, as presented in (Cadoz and Wanderley 2000). The term *gesture* is in Delalande's work divided into three levels; *effective*, *accompanying*<sup>17</sup> and *figurative*. This distinguishes between the movements necessary to produce the sound (effective gesture), the movements supporting the effective gesture (accompanying gesture), and an idea of a figurative gesture that is perceived by the audience but without a clear correspondence to sound-production. Cadoz & Wanderley (ibid) uses subcategories of the effective gestures to describe instrument control. These subcategories are *excitation gestures*, denoting the actions whose energy are causing the vibration that eventually result in sound, *modification gestures*, which are actions used to control the vibrations initiated by the excitation, and *selection gestures*, which to my understanding denote a choice, e.g. what methods to use for excitation and modification of the sound. In (Wanderley 1999) the *accompanying gestures* supporting the sound-producing movement are called *ancillary gestures*. These movements have a strong connection to the musical content, shown by a study where restricting performers from using these movements significantly influences the performance (Wanderley 2002). The ancillary gestures also have a semiotic function, i.e. the movements of the instrument are necessary for performers to communicate with each other and to/with the audience.

Godøy et al. (2006a) uses the term *sound-producing gestures* to denote the actions for sound excitation and modification mentioned above, *sound-tracing gestures* as movements imitating or following musical contours, and *amodal/effective/emotive gestures* for movements that may be related to aspects like feelings, emotions and mood. Godøy (2006b) includes the category *sound-accompanying gestures* as a category containing sound tracing, dancing, and other movements following the music. Godøy (ibid) presents a theory of *gestural-sonic objects*<sup>18</sup> which are fundamental for music perception. These gestural-sonic objects build on a continuous mental processing of features in music; features like the ones in Pierre Schaeffer's theory of the sonic object as presented

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17 Cadoz and Wanderley (2000) use the term *accompanist*. As pointed out by Jensenius (2007b: 41), *accompanying* is a better term, as the term *accompanist gesture* may be confused with the movements of an accompanist.

18 Godøy uses the terms *gestural-sonorous object* and *sonorous object* in (Godøy 2006b). In later publications (Godøy 2008), he uses the term *sonic object*. Thus, I have chosen to use the term *gestural-sonic object*.

above, where the music is chunked into units in our perception. The use of the prefix “gestural” to the sonic object is based on Schaeffer's description of sonic objects as either impulsive, sustained, or iterative, and directly linked to an *executive gesture* of the same type (Schaeffer 1998: 69). This is founded on ideas from embodied cognition, where the theory of perception, e.g. auditory input, is directly related to bodily movement, i.e. to what Godøy has denoted as *motor-mimesis* (Godøy 2003). Based on motor theory and recent neurocognitive research, Godøy presents a hypothesis that actions (which in a musical context are represented as gestural-sonic objects) are chunked in terms similar to Husserl's “now-point” (Godøy 2008). Godøy refers to research suggesting that human action, to a considerable extent, is pre-planned to certain *goal-postures* in time, which can be compared to key frames in animation, and a *prefix* and *suffix* which is movement between the goal points (ibid.). Godøy denotes the goal-postures in musical movement as *goal points*, where goal postures happen at downbeats or other salient points in time (ibid.).

Jensenius (2007b) discusses some difficulties with the term *gesture*, and he consequently uses *movement* to describe any change in position and *action* as a goal-directed, chunked movement, i.e. an entity only existing as result of cognitively segmenting the continuous movement into units. Jensenius presents a terminology summarizing many of the terms presented above, and implementing the use of movement and action instead of gesture. He uses term *sound-producing actions* in the same meaning as the term sound-producing gestures. *Ancillary movements* or *sound-facilitating movements* are, in Jensenius' terminology, movements of the type Wanderley (1999) calls ancillary gestures. *Sound accompanying actions/movements* are movements that imitate features in the sound. The theory behind these movements and the features in the sound can be understood in light of Godøy's gestural-sonic objects. Finally, Jensenius (2007b) uses the term *communicative movements* to describe movements without direct sound-producing functions. I interpret Jensenius' suggestion of using *action* and *movement* rather than *gesture* as an attempt to reach a common consensus on terms. I support this and will consequently use *action* and *movement* in my discussion.

The previous discussion shows two of the different perspectives in research on music-related movement. The research may focus on the performance, e.g. studying kinematics and playing technique of the performer for the reason of learning to learn more about musical performance. Research on music-related movement may also focus on perception. As discussed above, perceptual features of movement and the way we relate movement to what we perceive may explain the way we understand music. Both perspectives are relevant to the study of playing technique.

Jensenius' work on music and movement has had a major focus on developing new methods and technology for doing research in this field. The large variety of terms, and in particular the variety in sensors, motion capture systems and other input devices, has led to a need for consensus on

how to structure recordings of movement data. Jensenius et al. (2006) initiated the development of the Gesture Description Interchange Format (GDIF) as a format for storing and streaming data related to musical movement. This development has later been topic of several presentations and publications (e.g. Marshall et al. 2006 and Jensenius 2007a+b) and is still a work in progress.

The devices in use in research on music-related movement often communicate through different protocols and operate with different sample rates and bit resolutions. The GDIF development aims to standardize the way these types of data are represented. Jensenius (2007b) suggests a multi-layered approach, where several levels of data are available simultaneously. The suggested way of representing and communicating the layers is through the Open Sound Control<sup>19</sup> (OSC) protocol. In the OSC protocol, data is sent from a sender to a receiver with a namespace, e.g. an hierarchical address, for the data. Each level in the hierarchy is separated by a forward slash (/), and each of these levels may contain data or lower levels. As completely irrelevant, but lucid example of OSC namespace, we could leave musicology for a second and consider two flocks of birds. With two birds in each flock, we could describe the speed of each flock and the individual birds like this:

```
/flock1 <speed>
/flock1/bird1 <speed>
/flock1/bird2 <speed>
/flock2 <speed>
/flock2/bird1 <speed>
/flock2/bird2 <speed>
```

The layers suggested by Jensenius for the Gesture Description Interchange Format are as follows:

**Raw layer:** The raw data from the devices is stored to this layer. Due to different data ranges in different devices, the data in this layer is often not comparable between different devices.

However, when storing these data, it is always possible to retrieve the originally recorded data from the experiment if the need should arise. The suggested OSC-namespace for the raw layer is

```
/raw/name/<controller number> <value>
```

**Cooked layer:** In the cooked layer, the raw data is filtered to remove unwanted noise and scaled to a useful range to make data comparable between different devices. When the data refers to an already standardized measurement, the data in this layer should be scaled to the standard unit (e.g. cartesian position coordinates should refer to metric length units). The cooked layer namespace is closely related to the raw layer:

```
/cooked/name/<controller number> <value>
```

**Descriptive layers:** The descriptive layers contains analysed data from the lower layers, including the layers *device layer*, *body layer*, and *environment layer*. The data in these layers is relative to a

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<sup>19</sup> <http://www.opensoundcontrol.org>

specified perspective, e.g. data in the device layer is relative to a device, instrument, sensor, etc. and the recorded data is on this level used to describe something about the device. The namespace in the description layers can be quite complicated (for instance a body movement can be described on different levels – body, arm, hand, finger, joint, etc.), and thus I do not attempt to make a complete template for the description layers here, but use the following body layer example from Jensenius (2007b) of the right hand index finger pressing a joystick button:

```
/body/hand/right/finger/2/press <1/0>
```

**Functional and meta layers:** These layers are independent of the data in the lower-level layers.

The functional layers may include annotations describing the type of movement, and the meta layers may include higher-level interpretations of the meaning of the movement. There are no good definitions of the namespace and what to include in these layers, and Jensenius (2007b: 218f, 222) presents them as undefined and refers to plans for future research and collaboration with other ongoing projects focusing on music-annotations for a definition of these layers.

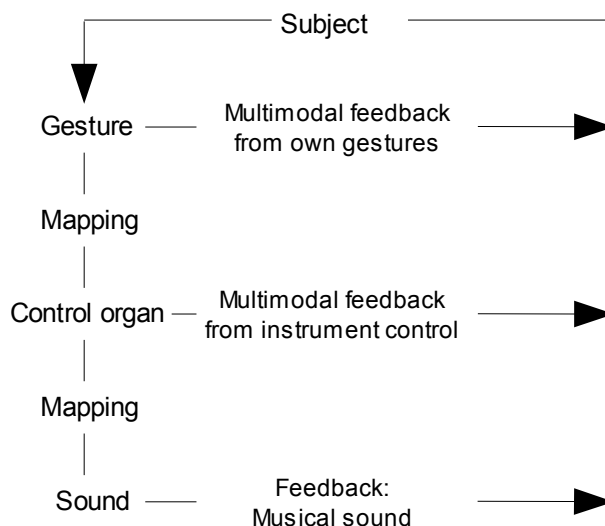
GDIF development is one of the fields where there is some confusion regarding the terminology. Marshall et al. (2006) separate movement data into raw data, body data and meta data, while Jensenius (2007b) uses the system in my example. I will not go deep into the differences in this terminology here, but when I later use these terms, I will explain what I mean by them.

Kvifte and Jensenius (2006) emphasises the need for description of actions to be able to describe instruments and playing technique, and GDIF development has been closely related to development of new musical instruments (Malloch et al. 2007). This especially counts for digital musical instruments where data from the instrument may be directly coded to OSC using a GDIF-based namespace.

Kvifte and Jensenius (2006) presents three perspectives for describing playing technique; the one of *the listener*, *the performer*, and the *instrument constructor*. Instead of using the term *listener*, which may be interpreted as referring exclusively to the auditory modality, I will here use the term *perceiver*, which implies that *listening* to music is really a multi-modal experience. From the perceiver's perspective, there is not necessarily a clear distinction between performer and the instrument. For example when the performer moves, the instrument may share the trajectory of the performer's movement. According to Kvifte and Jensenius the playing technique from the perceiver's perspective is mainly a focus of mapping actions to sound, without necessarily knowing the details of the mapping.

From the performer's perspective, playing technique is more detailed than from the perceiver's perspective, and the mapping of actions to control organs and control organs to musical para-

menters is essential. Figure 4 shows Kvifte and Jensenius' model of playing technique from this per-



**Figure 4:** Model of the performer's perspective, after (Kvifte and Jensenius 2006)

spective. As argued by Kvifte (1989: 63) the control organs are the parts of an instrument that, in light of playing technique, are of interest to a performer, and thus they are the only parts of the instrument shown in the model. The performer relies his/her control of the instrument on several types of feedback (visual, tactile/haptic and auditory) at several levels of the mapping chain. Kvifte and Jensenius (2006) argues that the study of playing technique from the performers perspective is only concerned with the *information* processing, and not the physical energy carrying the information.<sup>20</sup> Kvifte and Jensenius call this the *musical construction of an instrument*. Kvifte emphasises that a system for instrument classification based on playing technique should be based on these types of parameters, rather than the *technical construction* of the instrument (Kvifte and Jensenius 2006).

While the performer's interest in the instrument is focused on what to do with the control organs to get a desired musical result, the instrument constructor needs detailed information on the mappings within the instrument. This includes details on kinematics, i.e. the physical restrictions of the human body, and what control actions that can be performed. It also includes details on the different elements of the musical instrument and how they affect each other, e.g. how the energy and the information of the control actions are transformed into energy and information through the control organs, affecting the vibrations that eventually emerge as sound. This is a focus on technical parameters, or the *technical construction* of an instrument (ibid).

Just as the musical parameters are defined on different levels of measurement (see page 14 of this thesis), the other variables can be defined at different levels (ibid). Kvifte and Jensenius

<sup>20</sup> This type of information could for example be the musical parameter loudness (not the physics variable sound pressure level or amplitude), and what Kvifte and Jensenius calls a gestural parameter. For instance a highly accentuated attack to a piano key (not the physical force or velocity in the sound-producing action).

divide the term *control variables* into *gestural parameters* (which I call action parameters) and *technical parameters*. This allows separate descriptions of information *to* the control organs and *from* the control organs. Consider the action of hitting a piano key, the action parameter “accentuation” is a continuous parameter on the ordinal level. It is possible to say that an action is more or less accentuated, but from a musical perspective we can not make quantitative comparisons of the amount of accentuation. For the same action, the action parameter position is discrete and at the interval level.<sup>21,22</sup> The technical parameters related to the hammers moving and hitting the strings are usually not of interest to the performer, and thus when classifying instruments based on playing technique it makes little sense to talk about the accentuation of the hammer. But from the perspective of the constructor, the hammer would be an important part, described in terms related to the energy flow within the instrument (i.e. kinetic energy or velocity) rather than perceptual information terms.

## Summary

The theories presented above provide a good basis for an evaluation of the Nymophone2. During the discussions in the following chapters I shall frequently refer to the theory of music perception, playing technique and instrument description that has been presented in this chapter. In the next chapter I will present a technical description of the Nymophone2.

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21 This example is similar to the example presented in (Kvifte 1989: 100), where the movement of hitting a piano key is separated into three movement components; horizontally along the keyboard (H), across the keyboard (I) and vertically (V). The I component is not used in the case of the piano; so the two action components are the horizontal and vertical movement components H and V. I choose to use *position* rather than *movement* for the horizontal component because the horizontal velocity component of the hand is not of importance to pitch or loudness, whereas the position component is.

22 Position from a physical point of view is of course a continuous parameter, but for the action “hitting a piano key” the action parameter position is limited to the discrete choices presented to the performer by the keys of the piano.

## Chapter 3: The Nymophone2 – technical construction

In this chapter, I will first briefly outline the process of developing and constructing the Nymophone2, and present some of the challenges I have had to deal with. Then, in the section on physical properties of the Nymophone2, I give a detailed presentation of the final instrument. In addition to the figures in this chapter, I would like to refer to the more detailed figures in appendix A. The final part of this chapter presents the tools and methods I have used for sound analysis, and results from the analyses of the sound from the Nymophone2.

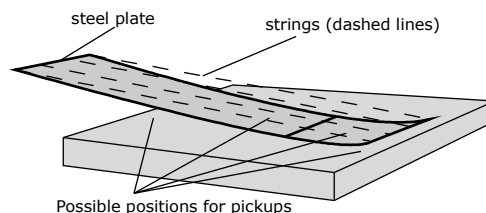
### 3.1 Development Process

Creating the Nymophone2 started as what seemed like a never ending process of trial and error. I was determined to create an instrument with a new sound, and had the idea of using a flexible metal plate in combination with strings. A metal worker gave me the first two steel plates to start with. They were both 1.5 mm thick and 50 cm long, one was 8 cm broad and the other one was 20 cm broad.

I mounted tuning machines<sup>23</sup> on both of the plates, and drilled holes for four strings on each of them. Then I put guitar strings on the plates, using thin, plain strings for the 8 cm plate, and thick, wound strings for the 20 cm plate. It was hard to tune the instrument in a reasonable way, but I managed to tighten the strings enough to make tones. The 8 cm plate turned out to be too thin; it bent too much and lost its tension. One of the plates, equipped with tuning machines and strings, is shown in figure 5. The tuning mechanism in this figure is not as sturdy as desired; the tuning machines are only connected to four pieces of polyethylene glued together, and a metal tie is wrapped around the polyethylene for holding it all in place. For the 8 cm plate I found a more rugged system, based on metal corner brackets.



**Figure 5:** The first prototype of the Nymophone2. This is the 50 cm × 20 cm version.



**Figure 6:** The first sketch of the instrument

Initially, my only consideration was the sound produced by the instrument, and so I did not pay much attention to playing technique. The strings on the 20 cm plate was mounted approxim-

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<sup>23</sup> Tuning machines are also called tuning pegs, tuning keys or machine heads.

ately 4 cm apart, something I rather quickly concluded was too far apart, as I had to move my whole lower arm to pluck different strings.

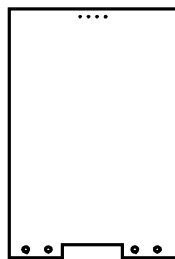
I presented the 20 cm prototype at the International Summer School in Systematic Musicology (ISSSM2007) at Ghent University. My plan at that point was to bolt the plate on a wooden board, like shown in figure 6. After my presentation at ISSSM2007, I discussed the idea with Alicja Knast from the University of Plymouth, who suggested that I mounted the plate on some sort of frame, since bolting it directly to a board would result in a loss of harmonic content. I had been aware of this problem, but had not thought about using a frame rather than a plain board. Starting off drawing different kinds of frames for the Nymophone2, I quickly discovered that I had to deal with problems regarding the location of the tuning machines, and the curving of the plate. The ideal frame would be a sturdy foundation which at the same time allowed the plate to vibrate as freely as possible, and it had to enhance, rather than limit, the player's possibilities in regard of different musical expressions and playing techniques. My solution was a frame where the plate was resting on each end, and was free to vibrate on the middle.

I wanted to be able to be able to control the pitch of the strings both by deforming the plate and by shortening the vibrating part of the strings with a guitar slide. I tried a guitar slide on the first prototype, and found that because the strings I had used were of the type where a material is wound around a steel core, the slide made quite a lot of noise. Because of this I chose to use plain strings on the final instrument

## 3.2 Physical Properties

### *The Plate*

The steel plate of the final Nymophone2 is 400 mm long, 250 mm broad and 1 mm thick. There are 4 holes for the strings (figure 7, top) with a diameter of 5 mm in one end of the plate, and there are copper eyelets in each hole. The centre of the holes are spaced approximately 19 mm apart and 1.1



*Figure 7: Plate. See appendix for details*

cm from the edge of the plate. The outer-most holes are placed 97 mm from the plate edges. The tuning mechanism is placed in the other end below the plate (figure 7, bottom). On the centre of this edge, there is a piece of polyethylene with indents for keeping the strings in place, and a smaller



piece of PVC<sup>24</sup> glued on top of this to keep the strings from cutting into the much softer polyethylene.

### *The Strings and the Tuning System*

Two steel corner brackets (figure 8) are holding the tuning machines. They are 75 mm long, 18 mm broad and 2 mm thick on both sides of the angle, and there are two holes on each side. The brackets



**Figure 8:** *Left: Corner brackets used for mounting the tuning machines, Right: rear end view of the tuning system* are mounted along the short side of the plate, 15 mm from the long sides, facing each other. The tuning machines on the Nymophone2 are ordinary tuning machines for an electric guitar. A softer material than the steel in the corner brackets was needed to attach these to the instrument. Thus, I mounted a small piece of polyethylene on both sides of the brackets. There are two tuning machines on each corner bracket, with the knob facing outwards, and the string-pins facing towards the centre (see figures in the appendix).

The strings used on the Nymophone2 are ordinary strings for electric guitar. The strings have a ball at the end holding it in place behind the holes in the plate. The thickness of the four strings on the Nymophone2 are 0.024" (0.61 mm), 0.016" (0.41 mm), 0.016" (0.41 mm) and 0.012" (0.30 mm).<sup>25</sup> The flexibility of the plate does naturally make the instrument hard to tune, as tuning one string up causes the plate to bend, thus the other strings are tuned down. I do not want to set any absolute rules for the tuning of the instrument, as it could be interesting to investigate different tunings, but for the experiments and measurements presented later in this thesis, the instrument has been tuned to an open A major seven chord.<sup>26</sup>

### *The Frame*

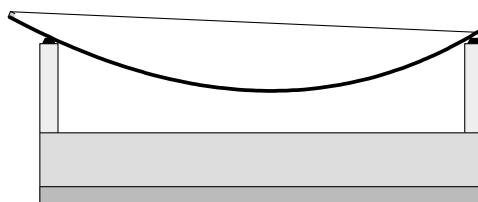
The frame is made out of oak wood. I have not given much thought to the choice of material, and chose this due to easy availability and low price at a local store. The reason for not putting more thought into this was that the purpose the frame was to support the plate, and to absorb as little as possible of the plate vibrations.

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<sup>24</sup> Polyvinyl chloride, a hard type of plastic.

<sup>25</sup> In my opinion, it is a good thing to stick to metric units, but string thickness is commonly given in inches.

<sup>26</sup> The pitch of the four strings were A, C#, E and G# (first to last string). I will return to details on the tuning below.



**Figure 9:** *The frame with the plate on top*

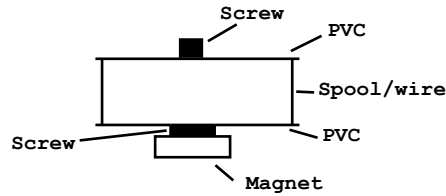
The frame is 368 mm long, which is slightly shorter than the plate. With this length the tuning system can be placed outside of the frame. Two boards are standing upright on each end. This is where the plate is connected to the frame. Between the frame and the plate, there is one small piece of rubber on one of the end boards, and two pieces of rubber on the other end board. The rubber pieces are there to remove distorted sounds which appear due to vibrations between the plate and the frame. The plate is bolted onto the frame at the end where there are two rubber pieces. This causes some change of the harmonic content, which is further discussed in the section on acoustic properties of the instrument. In spite of the alterations of harmonic content, which I initially was trying to avoid, I have chosen to bolt the plate to the frame to make sure that the plate stays in place. This prevents some wear and tear to the wires in the electronic system and makes the Nymophone2 sturdier and easier to handle.

In one of the end boards of the frame, there is a hole sized approximately 6 cm x 5 cm which is housing the main part of the electronic system. The hole is sealed with a 9 cm x 7 cm board on each side, this is displayed in the figures in appendix A2. Above this hole, on the inner side of the board is a small shelf for the lower pickup.

### ***The Electronics***

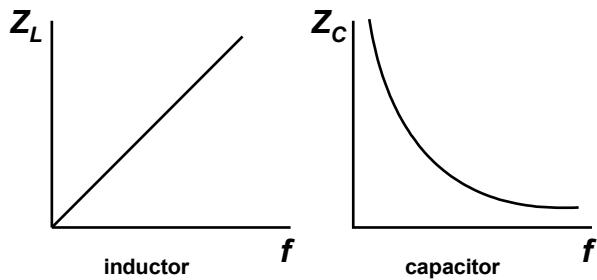
The Nymophone2 is equipped with a simple electronic system, similar to an ordinary electric guitar circuit. In this circuit, the phenomenon of electromagnetic induction causes the vibrations of the strings and the plate to be picked up and transformed into variations in voltage in the circuit. The transformer performing this operation is called an electromagnetic pickup, or simply “pickup”. A pickup consists of a magnetic field in combination with a small spool of conductive wire. When the magnetic flux through the spool is altered, a small voltage is induced in the spool.

The Nymophone2 has two pickups; one for picking up vibrations in the plate, and one for picking up vibrations in the strings. I refer to them as *plate pickup* and *string pickup*. I built the pickups from scratch, in order for them to fit as well as possible to the Nymophone2. The plate pickup has two small PVC plates kept approximately one cm apart by a screw through the centre of each plate. In one end of the screw (underneath the pickup) there is a strong neodymium magnet, which makes the screw function as a magnetic core in the pickup. The screw was first wrapped with

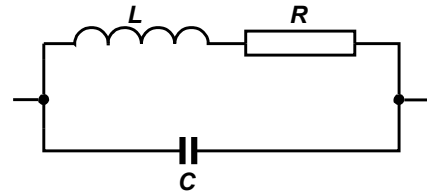


**Figure 10:** Sketch of the plate pickup

insulation tape, and then with a spool of 42-AWG copper wire.<sup>27</sup> The ends of the wire are soldered onto two eyelets in one of the PVC plates. The copper wire was spooled around the magnetic core, with an ordinary electric drill, fastening the pickup screw in the drill chuck. The string pickup is quite similar, the only difference being that the magnetic field consists of four equal screws with magnets underneath, all placed 18 mm apart to match the positions of the strings.



**Figure 11:** Impedance in inductors and capacitors



**Figure 12:** Electrical circuit of a pickup

The construction of the pickups does affect the sound from the instrument. In a spool carrying electrical current, there will be a capacitance between the turns of wire due to impedance in the wire and the turns of wire being very close to each other. In a capacitor, the impedance is inversely proportional to the frequency as displayed in figure 11 (Rossing et al. 2002: 405f). The coil itself is an inductor, where the impedance is proportional to the frequency of the alternating current (ibid). Thus the pickup is equivalent to a circuit of an inductor (the coil) and a resistance (due to the long distance of thin cable in the coil) coupled in parallel to a capacitor (capacitance between the turns), like in figure 12.<sup>28</sup> This results in a circuit with a resonance frequency given by

$$f_0 = \frac{1}{2\pi \sqrt{LC}} \quad (\text{Rossing et al. 2002: 412})$$

where  $L$  is the inductance of the coil (in *Henries*) and  $C$  is the capacitance between the windings (in *Farads*). I did not measure the resonance frequency of the pickups of the Nymophone2, and because I had no professional pickup winding tools, I did not have any good way of counting the number of windings in the spool. Thus I have not made any estimation or calculations of the pickup resonances, but it should be noted that the resonance of the two pickups take part in forming the

<sup>27</sup> AWG = American Wire Gauge, an American standard for wire thickness.

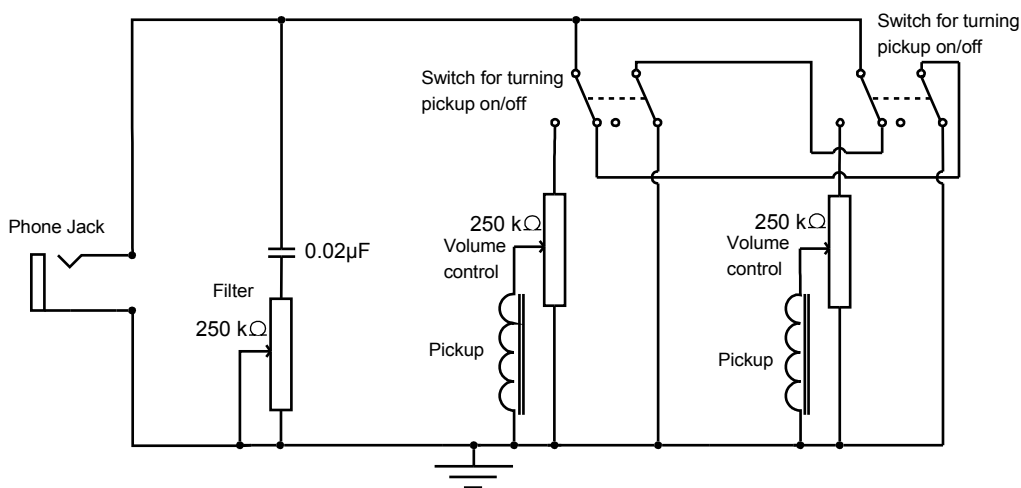
<sup>28</sup> I did not manage to find good, academic references to support this, but it is a well-known schematic for pickups, two examples of less academic references to this schema are:

[http://en.wikipedia.org/wiki/Pickup\\_\(music\)](http://en.wikipedia.org/wiki/Pickup_(music)) and [http://blueguitar.org/new/misc/gtr\\_lemme.pdf](http://blueguitar.org/new/misc/gtr_lemme.pdf) (accessed on 08.03.2008)

sound from the instrument.

The placement of the pickup does also affect the sound from the instrument. The harmonic content of the plate and the string vibrations are not equally distributed along the surface of the plate and the length of the string (Rossing et al 2002: 31, 292). Because of the spatial distribution of nodal lines and amplitude peaks in the vibrations, the pickups collect different variations of harmonic content depending on their placement. Because I focus more on the physical vibrations of the plate and strings than on electrical aspects in this thesis, I will not address pickup-related issues beyond these remarks.

Figure 13 shows the electric circuit in the instrument. Each pickup has a separate volume control knob, and a switch for cutting the pickup from the signal chain. To remove any noise, the live signal is sent directly to ground if both pickups are turned off. Finally, before the signal reaches the output phone jack, a combination of a capacitor and a variable resistor works as a low-pass filter. All the elements of this circuit are common in electric guitars, and should need no further explanation.



*Figure 13: The Nymphone2 electric circuit*

The electrical system of the Nymphone also includes an amplifier and optional effect modules. The Nymphone2 is not especially created for use with a specific type of amplifier or any specific effect modules. In the context of this thesis, the technical construction of amplifiers or effect modules is not important, and thus I do not include any details on such parts of the instrument in this chapter.

### **3.3 Acoustic Properties**

Kvifte (1989: 62) argues that the description of musical sound should not be done by physical variables. I interpret this as being in light of describing what Kvifte and Jensenius (2006) call the

*musical construction* of the instrument, rather than the *technical construction* of the instrument.<sup>29</sup> When describing playing technique as a musical activity, the sound achieved is interesting only within what Kivifte (1989: 61) calls the social field called “music”. Within this field the acoustic phenomenon produced by a performer and an instrument is given a meaning because of its relationship to other phenomena within this field, like music theory and visual aspects of a performance (ibid). However, from the perspective of an instrument constructor, physical variables are essential to understand the instrument (Kivifte and Jensenius 2006). The following documentation of acoustic properties of the Nymophone2 should not be regarded as a description of musical performance or playing technique, but a presentation of the technical construction of the instrument, which has been an important part of my work on the Nymophone2.

Because of my background in musicology, and since most acoustics literature that comes close to describing the phenomenon of a plate stressed by four different strings is hard to understand without years of mathematics and physics training, I have chosen to measure and analyse the instrument, rather than trying to mathematically estimate its acoustic properties through physical modeling. I present data extracted from the software I am using, and give examples of the plots I am using to extract this information. I have chosen not to include plots for every single piece of data, but I will describe how I extracted all the data I am working with from the sound files.

In my opinion, the two most interesting phenomena of the sound from the Nymophone2 are the stressed plate by itself and the interaction between the plate and the strings. The strings are less interesting by themselves because strings are well-known oscillators, with less complex harmonic patterns (Rossing et al. 2002: 31ff). Hence, I pay less attention to the string resonances.

### *Tools and method*

To analyse the sonic properties of the instrument, I am using the following software:

- Praat<sup>30</sup> by Paul Boersma and David Weenink,  
Dept. of Phonetic Sciences, University of Amsterdam
- Sonic Visualiser<sup>31</sup> by Chris Cannam,  
Centre for Digital Music, Queen Mary, University of London
- Spear<sup>32</sup> by Michael Klingbeil (Klingbeil 2005)

I have found it necessary to use several different kinds of software to get a broad perspective on the sound. The software uses different implementations of the Discrete Fourier Transform (DFT), and use different ways of representing the data. Thus they provide different information, useful for look-

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29 These terms are presented above, on page 21.

30 <http://www.fon.hum.uva.nl/praat/>

31 <http://www.sonicvisualiser.org/>

32 <http://www.klingbeil.com/spear/>

ing at different sonic features. They also include different features for processing the analysed sound. I will look into this shortly, but first I will briefly outline the theoretical problems related to this type of analysis.

In Discrete Fourier Transform the finite discrete signal with length  $n$  is analysed by regarding it as an infinite repetitive signal with period  $n$  (Roads 1996: 1092ff).<sup>33</sup> Each repetition may be reconstructed perfectly as a sum of sinusoids with frequencies of  $k \times f$ , where  $f$  is the frequency of a sinusoid completing exactly one cycle within the period  $n$  and  $k$  is an integer (Smith 1999: 150ff). The DFT provides information on frequency, amplitude and phase of the sinusoids which are present in the signal. In a spectrogram, this is done as multiple succeeding and/or overlapping calculations on a small part of the signal (Roads 1996: 563f). This gives information on the temporal evolution of harmonic content in the signal. Because the frequencies present in the signal are limited to integer-multiplications of the fundamental frequency in the time signal, the length of the analysed part of the signal (window length<sup>34</sup>) will determine the frequency resolution of the spectrogram, i.e. longer window lengths give better frequency resolutions but poorer temporal resolution. This problem is made slightly less prominent by using several overlapping windows, and different simultaneous window lengths, but this also leads to some “smearing” of both time and frequency.

*Praat* has been developed as software for studying phonetics, and features analysis tools especially made for voice analysis. It includes several functions, including a cochleagram displaying how the basilar membrane reacts to the sound, something which may be used for psychoacoustic evaluations. Using *Praat*, one may also extract a spectrum from the whole sound file, and export this as a text file with the parameters one wants to look at, e.g. the frequency bins and intensities. The weakest feature of *Praat* compared to *Sonic Visualizer* is that the plot axes do not include detailed information. That is to say it only displays the maximum and minimum values of each axis, in addition single, user-selected query value along the axis, while *Sonic Visualizer* displays continuous axis values, making it easier to read a printed plot. *Sonic Visualiser* is primarily an audio analysis tool for visualizing spectral features in sound files. It includes some processing-features like time-stretched playback and adding annotations to the sound file. In my use, the large variety in different spectrogram properties, and the good visualisation of these, has been the most important feature of *Sonic Visualizer*.

*Spear* is a software for both analysis and synthesis of sound. With this program it is possible to investigate the audio with an analysis-by-synthesis method. When importing an audio file into

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33 The other main types of Fourier analysis are Fourier Series, Discrete Time Fourier Transform and Fourier Transform. See (Smith 1999) for a comprehensive and detailed presentation.

34 Usually this length is referred to as window length. To extract only a small segment of the signal, the signal is multiplied by a function called a window.

*Spear*, it analyses a file based on certain user-defined settings, and resynthesizes the file based on sinusoids. It is then possible to remove or alter the sinusoidal components. This analysis-by-synthesis method for timbre is described in (Risset 1991) as an analysis based on perceptual criterion. *Spear* does not have the most elegant plotting functions, so my use of this program has been to verify the analysis of plate resonances by comparing the results from *Praat* and *Sonic Visualizer* to the sound from a *Spear* analysis.

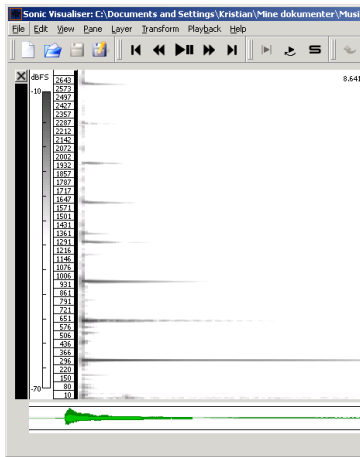
To make comparisons between two or more plots, I have used a technique which gives an intuitive display of the differences in the plots. I have done this because I sometimes find it hard to see the differences between plots when they are placed next to each other. I have called this technique *difference images*, and it is based on superposing plots where the axis units are identical. All of the audio analysis programs I am using can present equivalent plots of several audio files and where the screen output is represented in the same amount of pixels in one plot as in another plot. To get an idea of the differences in the two plots, each pixel in a screen shot of one plot may then be compared to the corresponding pixel in the other plot by using tools for graphical editing.

To make a *difference image* the plots are imported to separate image layers in a graphical editing software like Adobe Photoshop<sup>35</sup> or Paint.NET.<sup>36</sup> The parameters I am describing here have different names and ranges in different graphical editors, some giving values in percent and others in a 8 bit (0-255) range, but the functionality is still the same. To make the *difference image* from the two layers, I invert the colours of the top layer, and set the transparency level of this layer to 50%. This gives a grey image, where only the differences between the top and bottom layer is displayed. The axis values from the plots are equal, and so they are also greyed out. To display the axis values, I simply delete the part outside the plot of one of the layers. This process is displayed in figure 14. I do not address the significance of these example plots, but will look deeper into the meaning of this type of plots when I use them for analysis purposes.

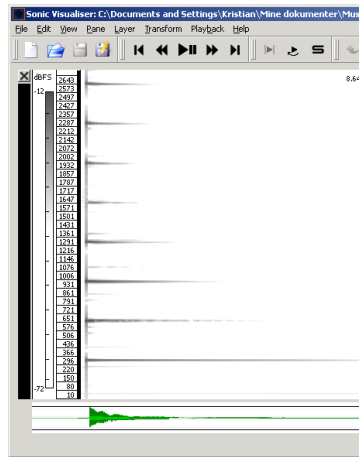
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35 <http://www.adobe.com/products/photoshop/index.html>

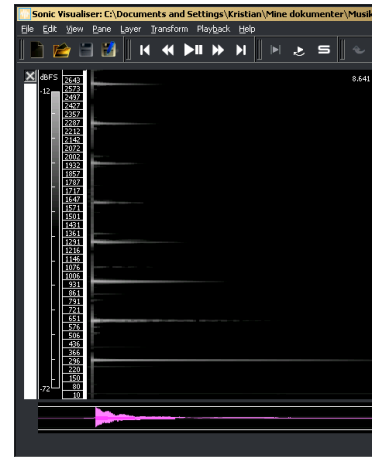
36 <http://www.getpaint.net>



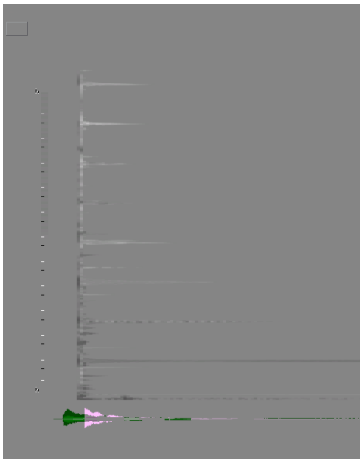
a. Screen shot A imported to bottom layer



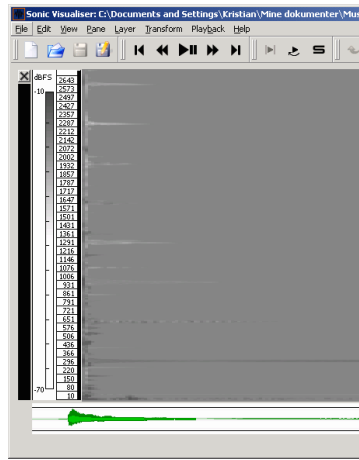
b. Screen shot B imported to top layer



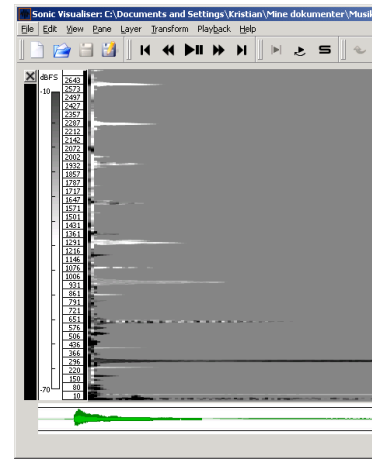
c. Top layer (B) inverted



d. Top layer made 50% transparent



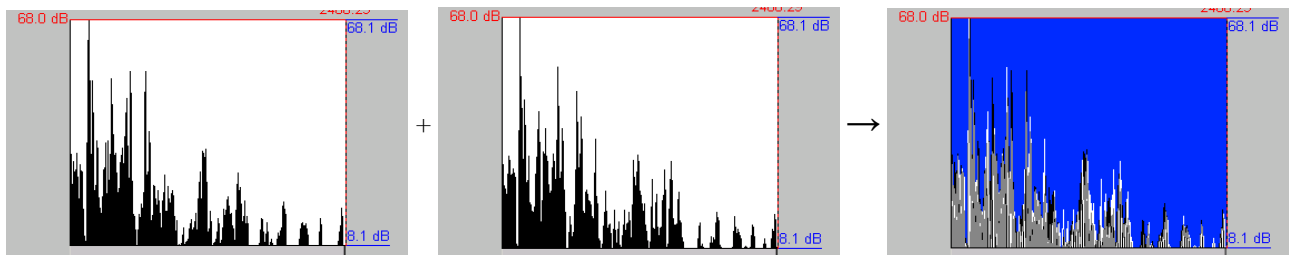
e. Non-plot area deleted from top layer



f. Plot-area contrast adjusted

**Figure 14:** Step-by-step difference image technique. The final image (f.) clearly shows that there are differences between the two plots A and B: The lowest fundamental is strongest in plot A (black), and the higher partials are stronger in plot B (white).

If the plots were originally displayed as black on white (binary), it is a good technique to remove the white background. A *difference image* like the one displayed in figure 14 can easily be misinterpreted, as it will not display plot information which is equal in the two original images. If the white background is initially removed and replaced by a common background (e.g. blue), one gets a plot where black/white still denotes differences between the two plots. Blue denotes similarity (no plot) and grey denotes similarity (plot). This is displayed in figure 15, and in better resolution in figure 18.



**Figure 15:** Difference image technique with distinction between types of equality. Blue = equal, grey = equal, black = difference, white = difference. See text for further explanation.



The *difference images* are mainly meant as a support to a qualitative evaluation of analysis plots. For quantitative evaluation one should use more sophisticated mathematical models for comparing plots.

It is necessary to mention that the plots presented here are normalized with regard to sound intensity for best graphical display. This means that it is not possible to compare the intensity of partials between different plots. Within a single plot, the intensity levels may be compared.

### Setup

I have recorded the sound from the Nymophone2 by plugging it directly into my computer. The instrument is meant to be played through an amplifier, but in this analysis I believe that recording the sound through a guitar amplifier and a microphone may be an unnecessary complication when analysing the plate-string system. For these recordings the instrument was tuned in an open A major 7 chord, i.e. A [ $\sim 220$  Hz], C# [ $\sim 277$  Hz], E [ $\sim 330$  Hz] and G# [ $\sim 415$  Hz].<sup>37</sup>

I have used different ways of putting the system into motion:

- hitting the plate (lightly) at various points with a soft mallet.
- bowing the plate at different points along the edges using a cello bow.
- plucking the strings with a finger.

The following techniques was used after the excitation of the system:

- letting the excited plate/string/system ring out.
- deforming the plate by pulling the strings.
- deforming the plate in various ways by pressing on it in different places.
- moving a slide along the strings to alter the length of the vibrating strings.
- damping the strings by touching them lightly.

The strings are damped in all the measurements where the focus is on the plate alone, and the plate is excited in its equilibrium state. When the plate is referred to as in “bent” state, but without annotations for the way it is bent, this is done by pulling the strings, which causes a deformation of the plate in one dimension. For all plate measurements, only the plate pickup has been used. Several of the sound files have been processed prior to the analysis. In such cases this is indicated in the text and in the figure caption. The audio files which are referred to in the figure captions are available from the “Audio Files - Figures” folder on the accompanying CD-ROM.

I must emphasize that these tests do not give a complete description of the resonances in the plate. But because I am testing different ways of exciting the system, I am confident that I do get

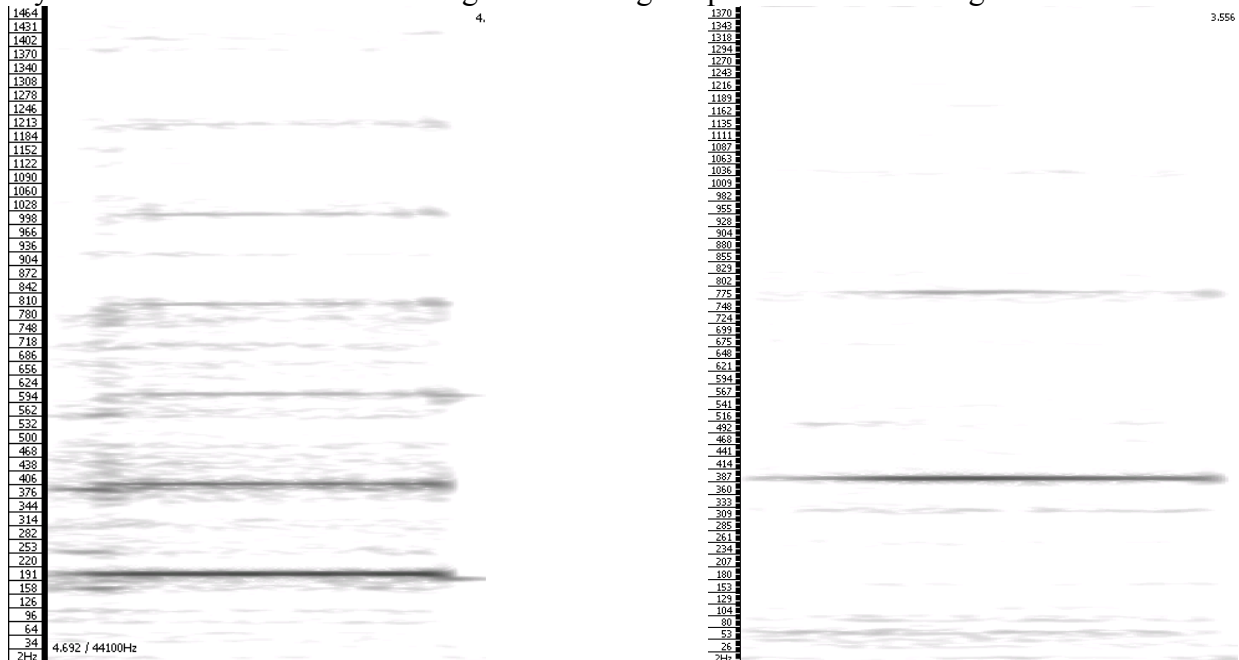
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<sup>37</sup> The frequencies are approximate, and hard to measure on this instrument due to interplay between the string vibrations and the plate vibrations. An analysis in *Praat* output varying values during attack and decay of a single string being played: The lowest string, A, varying between 219.6 Hz and 223.9 Hz, C#-string between 277.0 and 278.8 Hz, E-string between 328.8 Hz and 331.0 Hz, and G#-string between 414.8 Hz and 415.7 Hz.

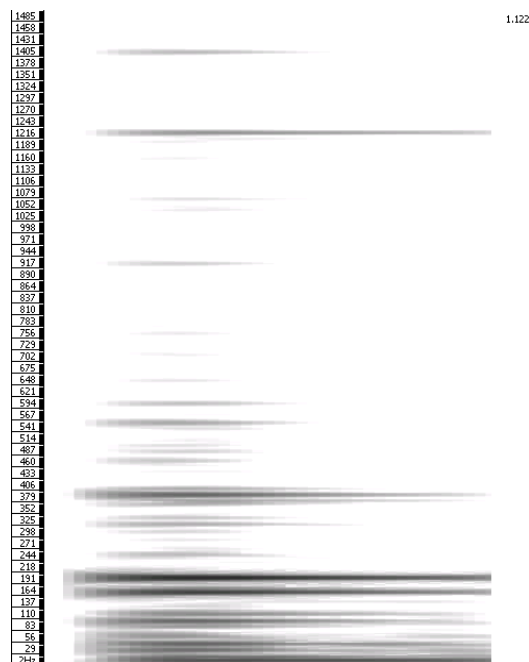
measurements good enough to investigate the interplay between the different components in the Nymophone2.

## Measurements

By bowing the plate, it is possible to make the plate resonate at several frequencies. Spectrogram analyses of two of the sounds resulting from bowing the plate are shown in figure 16.



**Figure 16:** Spectrograms of two of the audio file recordings of bowing the plate. The sound files are available from the “Audio Files - Figures” folder on the CD-ROM. Left: “Figure16a.wav”. Right: “Figure16b.wav”

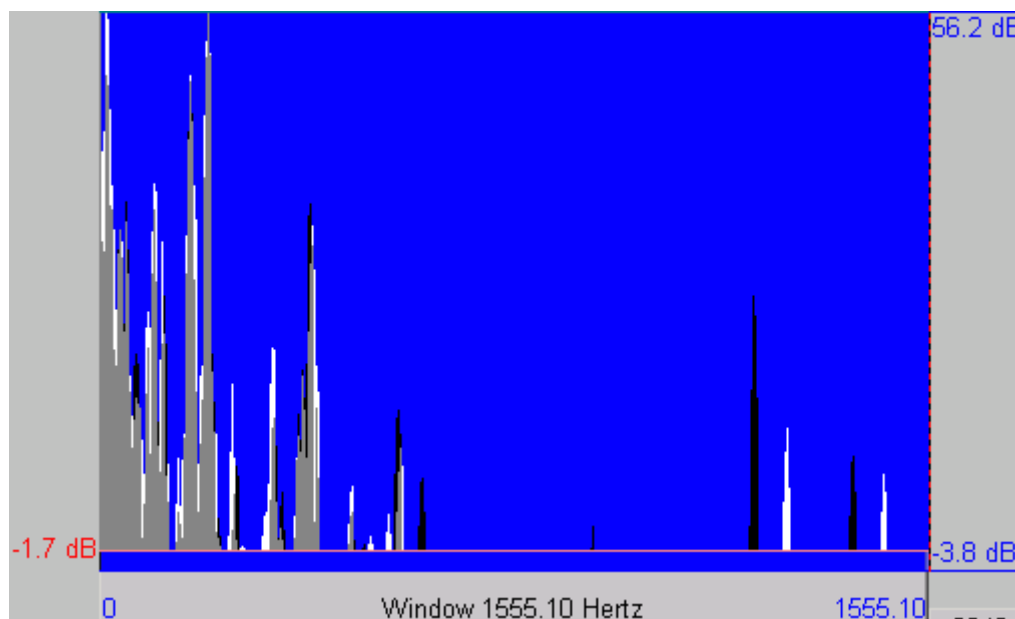


**Figure 17:** Spectrogram analysis of a sound from hitting the plate with a mallet. The attack part of the sound is removed. Sound file: “Figure17.wav”

By running a pitch algorithm in *Praat*, I found that the tones resulting from bowing the plate had the following fundamental frequencies:<sup>38</sup> 174 Hz (in figure 16, left), 204 Hz, 395 Hz (figure 16, right), 1161 Hz, 1230 Hz and 3743 Hz. A complete list of audio files and plate resonances is given in table 1 on page 37.

The plate resonances are strongest at the fundamentals, but with each of the fundamentals mentioned above comes a set of higher partials. The harmonic patterns of the resonances found by bowing the plate seem to a certain extent to follow harmonic series. This is shown in the leftmost spectrogram in figure 16. This spectrogram also shows a few inharmonic partials, at about 720 Hz and 930 Hz, but the resonances at about 200 Hz, 400 Hz, 600 Hz etc. are much more prominent.

Hitting the plate results in sounds where several of the harmonics found above are present. Figure 17 shows a spectrogram analysis of the sound resulting from the plate being hit by a mallet. To be able to look at only the sustained partials in the sound, the attack-part of the sound is removed. The spectrogram shows distinct partials around 170 Hz, 200 Hz, 400 Hz, 1230 Hz and 1420 Hz, in addition to a couple of less distinct partials around 560 Hz, 600 Hz, 930 Hz, 1060 Hz and 1160 Hz. These values are the peak bins from the Sonic Visualiser spectrogram analysis displayed in figure 17.

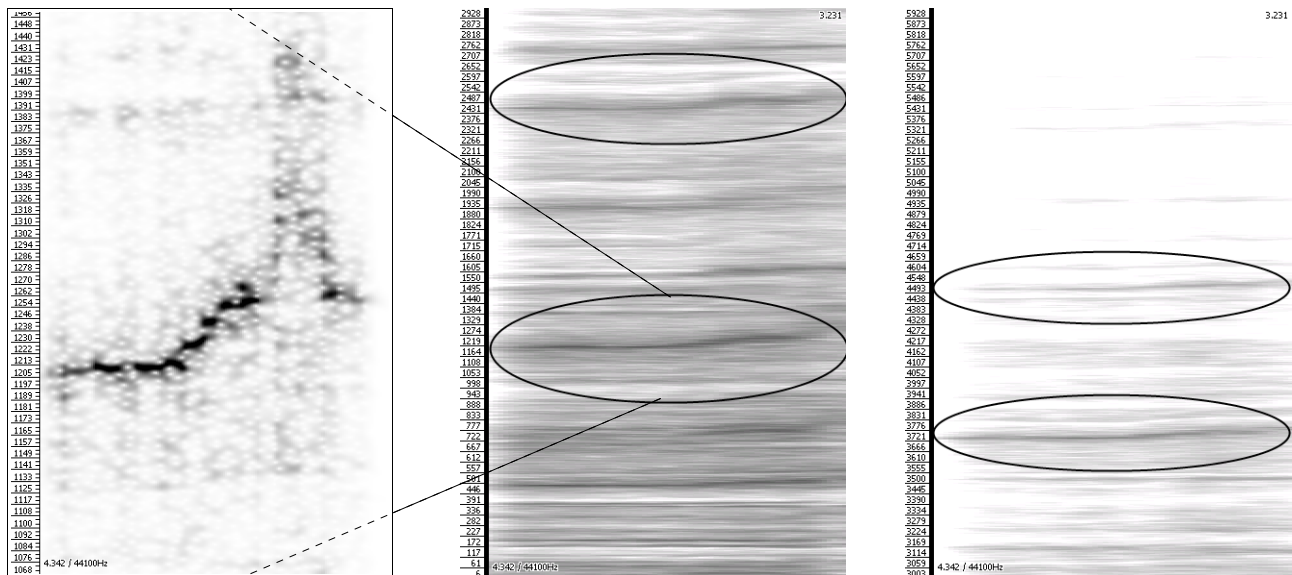


**Figure 18:** Comparison of the equilibrium and bent states of the sound from a plate being hit by a mallet with the attack part of the sound removed. The sound from the equilibrium state ("Figure18a.wav") is the same sound as is displayed in figure 17. "Figure18b.wav" is the sound file of the plate in the bent state. The plot shows frequencies from 0 Hz to 1555.10 Hz. The grey area displays harmonic content present in both states, the black area is harmonic content only present in the equilibrium state and the white area displays harmonic content only present in the bent state. This difference image is made in the graphics editor *Paint.net* from two equally displayed spectra generated by *Praat*. The plots are not placed directly on top of each other, but adjusted in height to compensate for different maximum and minimum values (but identical range) on the sound intensity axis.

<sup>38</sup> Fundamental frequencies here denotes the lowest harmonic in the series of overtones resulting from bowing the plate. The frequency values were extracted from an algorithm in *Praat*, i.e. not manually read from plots like the ones in figure 16. These plots are merely meant as illustrations of the harmonic series in the sound.

The effect of bending the plate is evident across the whole frequency spectrum. Figure 18 shows a *difference image* of frequency plots of the hitting the plate with a mallet in bent and equilibrium states, with the attack part of the sound removed. This *difference image* shows that the lowest partials are slightly lowered by bending the plate, and the highest partials are higher in the bent state. The two partials of highest frequency in this plot are 1229 Hz and 1415 Hz in the equilibrium state, and 1291 Hz and 1473 Hz in the bent state.

Figure 19 show spectrogram analysis of the plate being bowed lightly, resulting in a noise-like sound. The plate is gradually bent in one dimension during the duration of the sound displayed in the spectrogram. The plot shows that the partials in equilibrium state gradually adjust to another frequency in the bent state. This gives good reason to believe that the two partials from the bent and equilibrium states that are close in frequency are due to the same vibration mode in the plate. The partials around 1230 Hz, 2450 Hz, 3740 Hz and 4520 Hz (outlined in the figure) seem to be the partials most affected by bending the plate. In this spectrogram the partial around 1400 Hz does not appear. I am not sure of the reason for this, it may be due to the plate being excited at a nodal line of this partial.



**Figure 19:** Spectrogram of plate being bowed lightly ("Figure19.wav"). The plate is bent by pulling the strings on the middle of the spectrograms. The middle and right spectrograms are of different frequency ranges: middle 0Hz-3kHz and right 3kHz-6kHz. The left spectrogram is a high-frequency-resolution, dynamically normalised version of the lower of the two outlined resonances in the middle spectrogram.

Table 1 shows a summary of resonances in the plate in equilibrium and bent state. The table shows that there are great differences in to what extent bending the plate affects the resonances. While the lower resonances tend to be lowered slightly, the resonances of higher frequency are more affected.

Equilibrium	Bent	Found by	Audio files
104 Hz	104 Hz	Praat - peak	plate_hit_1_noattack.wav and plate_hit_1b_noattack.wav
174 Hz	170 Hz	Praat - pitch	plate_bow_3.wav and plate_bow_3b.wav
204 Hz	202 Hz	Praat - pitch	plate_bow_1.wav and plate_bow_1b.wav
328 Hz	326 Hz	Praat - peak	plate_hit_1_noattack.wav and plate_hit_1b_noattack.wav
395 Hz	400 Hz	Praat - pitch	plate_bow_7.wav and plate_bow_7b.wav
561 Hz	565 Hz	Praat - peak	plate_hit_1_noattack.wav and plate_hit_1b_noattack.wav
1161 Hz	1484 Hz <sup>39</sup>	Praat - pitch	plate_bow_8.wav and plate_bow_8b.wav
1230 Hz	1327 Hz <sup>39</sup>	Praat - pitch	plate_bow_5.wav and plate_bow_5b.wav
1415 Hz	1473 Hz	Praat - peak	plate_hit_1_noattack.wav and plate_hit_1b_noattack.wav
2450 Hz	2500 Hz	SV - read	plate_bownoise_sb.wav
3743 Hz	None <sup>40</sup>	Praat - pitch	plate_bow_6.wav
4520 Hz	4550 Hz	SV - read	plate_bownoise_sb.wav

**Table 1:** List of the most prominent resonances in the Nymphone2 steel plate. The columns “Found by” and “Audio files” indicate the method and which audio file that is used for finding the resonance:

*Praat - pitch:* Fundamentals extracted by the pitch algorithm in Praat.

*Praat - peak:* Peak bins extracted from Praat spectrum.

*SV - read:* Pitch bins from Sonic Visualizer spectrogram.

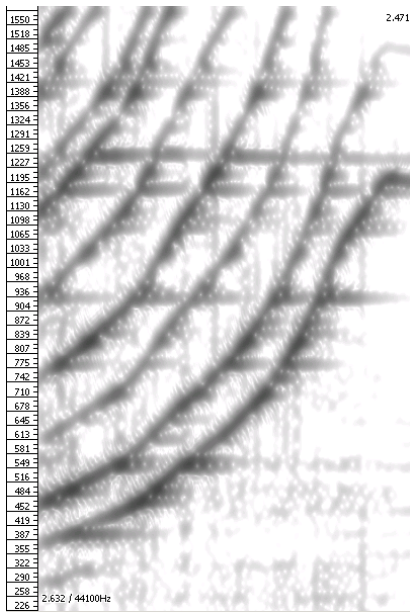
Most of these resonances are shown in all the methods I have used (with small differences in frequency, depending on the Fourier Transform properties). In the cases where several methods show the same resonance, only one method is referred to; which of them is rather random.

The effect of interaction between the strings and the plate is clearly shown in figure 20. This is a spectrogram of a sound resulting from plucking all strings at once, and then gradually moving a slide up the strings to shorten the vibrating parts of the stings. Before this analysis, the attack part of the sound was removed, a high-pass filter was applied at 130 Hz and the sound was dynamically compressed through an ordinary audio dynamics compressor to get a good view of harmonic content in the audio file from beginning to end. Only the plate pickup was used during the recording. The figure displays the plate resonating whenever one of the partials from the string vibrations is equal to the plate resonances. The ~1230 Hz and ~1160 resonances are the most prominent in the plot, because the string partials are close to these frequencies at all times during the time span displayed. If the strings would have vibrated at lower frequencies, it is likely that lower plate resonances would have been equally prominent in the plot.

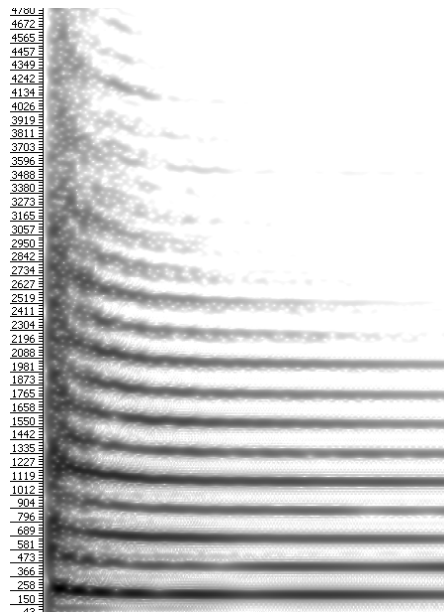
Due to the flexibility of the plate, the vibration of a string is not necessarily constant in terms of frequency. Figure 21 shows a plot of the perceived pitch (from *Praat*) and a spectrogram of the sound from the string pickup when a string is being plucked with high velocity and force. No

39 These values in the bent state was found by bowing the plate at the same point as when it was in the equilibrium state. They diverge much from the equilibrium states, and may very well be another mode of vibration as the nodal lines may have been displaced by bending the plate. If one looks at values from gradually bending the plate (e.g. figure 19), one gets results closer to the equilibrium state (about 1270 Hz for the 1230 Hz resonance).

40 I did not manage to make the plate resonate at any distinct frequency by bowing at this position in the bent state. (The sound was noise rather than a tone). This may be due to alterations of the nodal lines when the plate is bent.



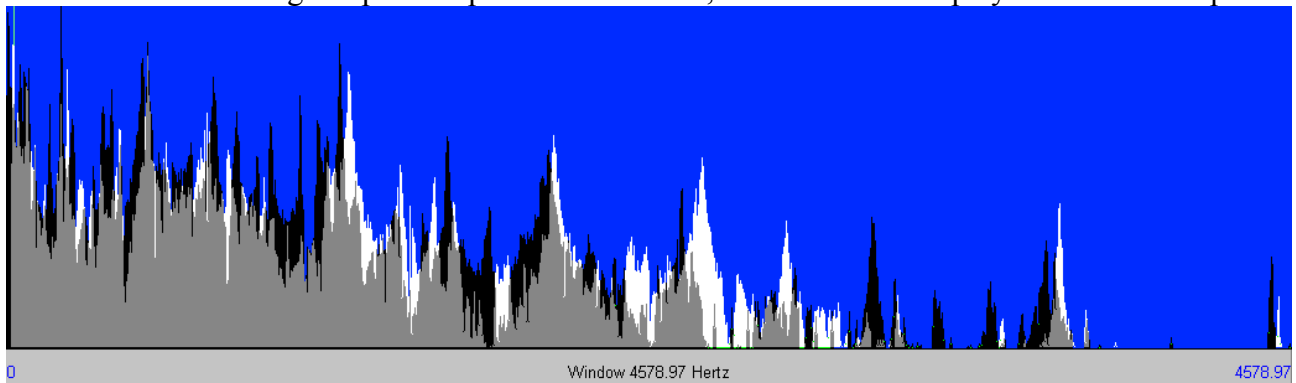
**Figure 20:** Spectrogram analysis of a major seven chord glissando (all strings simultaneously).



**Figure 21:** Spectrogram (left) and plot of perceived pitch (right) of the sound from highly accentuated A string.

other control action than the highly accentuated plucking was performed. It is obvious from these plots that the force applied when a string is plucked affects the pitch and timbral envelopes. An analysis in *Praat* gives the maximum value for the perceived pitch during the time span of the sound to be 279 Hz and the minimum value to be 219 Hz.

My final consideration for the physical vibrations in the instrument is the effect of bolting the plate to the frame. Figure 22 shows a *difference image* of the frequency spectrum of the noise-like sound resulting from bowing the plate lightly. The black part of the spectrum is from the sound when the bolts holding the plate in place are removed, and the sound displayed in the white plot is



**Figure 22:** Difference image of average spectra of sound from lightly bowing the the plate when vibrating (almost) freely, and being bolted to the frame. The black plot is the free vibrations (audio file: "Figure22a.wav") and the white is the vibrations from the bolted plate (audio file: "Figure22b.wav").

from the plate being fixed to the frame. Some resonances seem to be raised in terms of when the plate is bolted to the frame, and some resonances seem to disappear. As previously stated, I chose to fix the plate to the frame to prevent damage to the instrument during transport, or even during performance.

## Chapter 4: Playing technique from a GDIF perspective

To test the Nymophone2 in a musical context, I have made several recordings of a subject improvising on the instrument. This subject was chosen because of his background and experience with improvised music. The subject is a guitarist, so he did have good experience playing a string instrument prior to the recordings, nevertheless most of the control variables related to performance on the Nymophone2 was completely new to the subject at the time of the first recordings. Results from these recordings are presented here mainly for the purpose of illustrating playing technique for the instrument, and is not to be interpreted as an empirical study of the playing technique on the Nymophone2.

In addition to illustrate playing technique on the Nymophone2, my goal with these recordings is to illustrate a GDIF approach to recording and processing of movement-related data. The methods described in this chapter are therefore presented using terms from the GDIF development. Much of the research on new digital musical instruments focus on the actions performed on the instrument, one example being the *T-Stick* by Joseph Malloch (Malloch and Wanderley 2007). The raw data from the sensors in the T-Stick is mapped to a higher-level layer with information on how the performer is moving, and further on to an audio synthesis layer. In this example the GDIF device layer contains data on features relating to the instrument, and these features may often be extracted directly from the instrument data. As examples of the layers presented in chapter 2, the body layer could be used for data related to the movements of the performer, and the functional layer could include annotations that are not necessarily easy to read from the raw data alone.

By recording the performance using the GDIF approach, all the data from the instrument, the sound, video, and annotations are accessible simultaneously, and thus I do believe that a GDIF approach may be useful to get a deeper understanding of the playing technique of instruments.

This chapter presents the recording setup, the processing of data and the adding of annotations (i.e. subjective judgements of the performance) to the recorded file. I met several obstacles during the analysis of the data, and these issues are presented in the text. The analysed data is used to illustrate playing technique for the Nymophone2 in the end of this chapter and in the section on playing technique in chapter 5.

### 4.1 Experiment: recording the raw GDIF layer

The recordings were done in the Musical Gestures lab at the University of Oslo. They took place in three similar sessions, as displayed in table 2.

Session	Experience	Session layout
First session	No experience	<ul style="list-style-type: none"> <li>• First try / investigation</li> <li>• Improvisation alone</li> <li>• Improvisation with accompanying guitar</li> <li>• Playing simple children's tune</li> </ul>
Second session	A few hours practice	<ul style="list-style-type: none"> <li>• Improvisation alone</li> <li>• Improvisation with accompanying guitar</li> <li>• Playing simple children's tune</li> </ul>
Third session	A few weeks practice	<ul style="list-style-type: none"> <li>• Improvisation alone</li> <li>• Improvisation with accompanying guitar</li> <li>• Playing simple children's tune</li> </ul>

**Table 2:** Overview of performance sessions on the Nymophone2.

The first session was recorded when the subject had no previous experience playing the instrument. The second session was recorded later the same day, when the subject had spent a few hours practising, and the third session was done a few weeks later, after more practice.<sup>41</sup> All three sessions included a solo improvisation, an accompanied improvisation and the playing of the children's tune “Itsy Bitsy Spider”. The latter was chosen because it is a simple, well-known (in both Norwegian and English cultures) song, with a rather large range of tones compared to other simple children's tunes. In addition to these three parts, the first session included a short period of first-try-exploring of the instrument. The Nymophone2 was amplified by a Fender Deluxe Reverb amplifier, and the subject was playing standing, with the Nymophone2 on a table in front of him. In the third recording session, the instrument was expanded with a Line 6 Echo Park delay module.<sup>42</sup> My initial idea for the recordings was to illustrate development of a playing technique by looking at the differences between the different recordings. However, due to poor data from some of the sensors in the first two recording session (this is discussed in the pre-processing section below), and due to problems analysing the great amount of data, I have chosen to focus on the last session, especially on the recording of the solo improvisation.

The performances were recorded using a setup from an ongoing research project at the University of Oslo (Jensenius et al. 2008). In the recordings of Nymophone2 performances, I used the following equipment:

- 9 Phidgets 3D USB accelerometers
- Polhemus Patriot electromagnetic tracking system with 2 sensors
- 2 Infusion Systems BioFlex EMG sensors
- 2 video cameras (one Unibrain high-speed 86fps camera, and one Sony HD camera)
- 1 microphone

<sup>41</sup> I have no measurement for the actual time spent practising on the instrument. The subject did this on a voluntary basis, so I do not expect that he practised for several hours every day. It is anyway safe to conclude that the third session was done with the subject having practised much more than in the other two sessions.

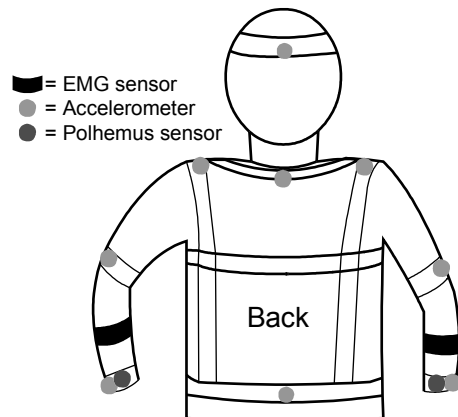
<sup>42</sup> <http://line6.com/tonecore/echoPark.html>



For this setup, I made an adjustable strap-on system to attach sensors to the upper body of the subject. One accelerometer was placed on the head, one on the neck, one on each shoulder, one on each elbow, one on each wrist and one on the lower back of the subject. The two Polhemus Patriot sensors were placed next to the accelerometers on the wrists, and the two BioFlex sensors were placed on the lower arms. This is displayed in figure 23.

The data from the sensors and pre-processing of these data is presented in the next section. As an overview of the recorded data, I display the namespace in the raw GDIF layer:

```
/raw
/accelerometer/1 x y z
/accelerometer/2 x y z
/accelerometer/3 x y z
/accelerometer/4 x y z
/accelerometer/5 x y z
/accelerometer/6 x y z
/accelerometer/7 x y z
/accelerometer/8 x y z
/accelerometer/9 x y z
/polhemus/1 x y z azimuth elevation roll
/polhemus/2 x y z azimuth elevation roll
/bioflex/1 value
/bioflex/2 value
/audio_video/record on_off
```



**Figure 23:** Strap-on system for accelerometers, EMG and Polhemus Patriot sensors

The audio and the video from the Unibrain camera were recorded to a Mac Pro, and the data from all the sensors was recorded to a Windows PC. Using several types of data with different sample rates, and recording audio/video and numerical data to separate computers, is challenging in regard of synchronizing the data. To deal with these problems I recorded the GDIF data to separate SDIF<sup>43</sup> streams, as suggested in (Jensenius 2007b) and (Jensenius et al. 2008). The SDIF format provides a good framework for recording different types of data to a common timeline, and thus makes it easy to synchronize the recordings when the data is to be analysed.

I have developed a set of Jamoma<sup>44</sup> modules for recording to, and playing back, movement data from SDIF files. The purpose of using SDIF as a container format for the GDIF data, and more information on the Jamoma SDIF modules I have developed is found in (Nymoen 2008).

## 4.2 Processing: the cooked and descriptive layers

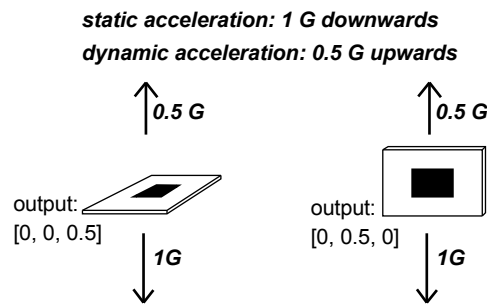
Before being able to analyse the data from the sensors, a great deal of pre-processing was necessary.

<sup>43</sup> The Sound Description Interchange Format has been developed at IRCAM and CNMAT as a format for storing and streaming various representations of a sound file. See (Wright et al. 1998) for details.

<sup>44</sup> Jamoma (<http://www.jamoma.org>) is a standardized way of building high level modules for Max/MSP/Jitter (<http://www.cycling74.com>), which provides several solutions for user interface, including GUI, presets and ramping of parameters.

The methods presented here for pre-processing data are well-known methods for signal processing, and so I will not present them in detail.<sup>45</sup>

The accelerometers output both static and dynamic acceleration.<sup>46</sup> This means that part of



**Figure 24:** *Ambiguity in accelerometer data*

the accelerometer data is due to gravity and part of the data is due to change in velocity. The data is in units of gravities ( $\sim 9.81 \text{ m/s}^2$ ), and it is output as three sets of acceleration values relative to the accelerometer (X, Y and Z axis). Because the data is relative to the accelerometer, the output from the accelerometer will depend on how the accelerometer is placed on the subject. For instance, an accelerometer output of  $[0, 0, 0.5]$  from one accelerometer may be equivalent to  $[0, 0.5, 0]$  from another accelerometer, as displayed in figure 24. The problem of an ambiguous accelerometer output from different accelerometer orientations can be solved by reducing the three cartesian coordinates from the accelerometer to a single value consisting of the magnitude of the vector the three coordinates represent. My interpretation of the resultant variable is discussed below.

The static acceleration appears in my use as an unwanted offset. To remove this offset, I calculate the derivative of the data. This does only remove the tilt offset as long as the accelerometer is not rotated, so it is important to note this as a potential source of misleading data. However, I assume that any change in static accelerometer data is likely to take place at the same time as change in motion data. To filter out unwanted noise from the accelerometer, I applied a low-pass filter to the raw accelerometer data. The filtering and derivation of the data was done on the raw cartesian coordinates, i.e. prior to extracting the vector magnitudes. Finally, the processed data was normalised to a 0-1 range. All values from the accelerometers were normalised using the same maximum values; e.g. if the values from accelerometer 1 was between 0 and 4, and the values from accelerometer 2 was between 0 and 2, the normalised accelerometer 1 values would be between 0 and 1, and the accelerometer 2 values would be between 0 and 0.5.

The Polhemus raw data is by nature less problematic, as orientation data and position data are separated. However, in the first two recording sessions, the recorded data from the Polhemus was not very good. When playing on the instrument, the two Polhemus sensors were alternating

<sup>45</sup> Thanks to A. R. Jensenius for suggestions on methods for pre-processing data from the sensors.

<sup>46</sup> <http://www.phidgets.com/documentation/Phidgets/1059.pdf>

between being inside and outside the electromagnetic field within which they must be for the Polhemus system to be able to track their position. Thus, the Polhemus data is not as useful in the two first recording sessions. The Polhemus outputs six variables per package per sensor; position as cartesian coordinates (X, Y, Z) in units of inches, and orientation in degrees (azimuth, elevation, roll). In the pre-processing of these data, I applied a low-pass filter to all six variables and converted the position variables to metres. I do not find the exact orientation of the sensors to be as interesting as the total amount of rotation at each time, so I calculated the derivative of the vector magnitude of the three orientation coordinates, to get a measure of the current rotation of the sensors.<sup>47</sup> These values were normalised to a 0-1 range.

The documentation of the BioFlex<sup>48</sup> sensors says that EMG data consist of bursts of alternating current resulting from muscle contractions, but this documentation does not include much information on the data from the sensors. The data from the sensors seem to be alternating below and above a value of 60. By calculating the absolute value of the derivative of the EMG signal, the data stream from the sensors seem to follow finger movements and muscle contractions. When there is low muscle activity the value is close to zero, and values rise with higher muscle activity. I have chosen to use this method to pre-process the EMG data, as it appears to be a valid interpretation of the data. In my setup, I recorded the EMG at a low sample rate (10 Hz), which makes comparisons of time differences between the EMG data and the other sensors hard. I did unfortunately not think of this during the recordings, but noticed this during the analysis process. I have chosen to still include the EMG data in the higher layers, but find it hard to draw any clear conclusions based on these data.

After pre-processing, most of the data is normalised to a 0-1 range. The only exception is the Polhemus position data, which is in units of metres. The raw data was played back through an algorithm for pre-processing the data and the pre-processed data was recorded to a new file with the Jamoma sdif.record module (figure 25).

The namespace of the pre-processed data in the cooked layer is shown below. The difference from the raw data layer is that the accelerometers are represented by only one value, polhemus data has been separated into 3D position and 1D rotation, and all the data is scaled as presented above.

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<sup>47</sup> Rotation being the derivative of orientation (equivalent to velocity being the derivative of position)

<sup>48</sup> <http://infusionsystems.com/support/BioFlex-guide-10.pdf>

```

/cooked
/accelerometer/1 [0. 1.]
/accelerometer/2 [0. 1.]
/accelerometer/3 [0. 1.]
/accelerometer/4 [0. 1.]
/accelerometer/5 [0. 1.]
/accelerometer/6 [0. 1.]
/accelerometer/7 [0. 1.]
/accelerometer/8 [0. 1.]
/accelerometer/9 [0. 1.]
/polhemus/1/position <x y z> [-1.5 . 1.5]
/polhemus/1/rotation [0. 1.]
/polhemus/2/position <x y z> [-1.5 . 1.5]
/polhemus/2/rotation [0. 1.]
/bioflex/1/value [0. 1.]
/bioflex/2/value [0. 1.]
/audio_video/record [0 1]

```



**Figure 25:** Method for recording higher-level GDIF layers (not the actual patcher used)

In my setup, I made a third file where data from the descriptive and functional layers are found. In this file I relate the sensor data to the performer (body layer), and add annotations to the recorded file. The sensor data from the pre-processing presented above may be directly transferred to body-related data in the descriptive GDIF layer. The accelerometer values are applied to the part of the body where the accelerometer was placed, and the value in the range 0. to 1. gives an indication of the acceleration in that part of the body. Position values (in metres) and rotation values (0 to 1) are assigned to the wrists using the Polhemus values, and the EMG values are assigned to the left and right arm as measures of “muscle activity”. Using the motion analysis tools provided with Jamoma, I extracted values for quantity of motion from the video-recording, and recorded this into a separate stream. To add performance annotations to the file, I recorded a stream as integers where each integer refers to a row in a look-up-table, which was written to the header of the SDIF file. The second column of this table contains the verbal annotations. The look-up-table is displayed as a small text-window in the screen shot in figure 26. The recorded annotations concerned various aspects of the performance. I recorded an annotation for whether or not the delay module was turned on and an annotation for whether the subject was playing on the delay module or on the Nymophone2. Next, to be able to analyse the recorded data in regard of performance intensity, I recorded my subjective evaluation of performance intensity in three levels (low, medium and high intensity), and finally annotations for when three control actions for the plate was performed; bending the plate, vibrating/shaking the plate and tapping the plate. The namespace for the descriptive layer in my GDIF-file, is as follows:

```

/body
/neck/acceleration [0. 1.]
/back/acceleration [0. 1.]
/arm
  /left/shoulder/acceleration [0. 1.]
  /left/elbow/acceleration [0. 1.]
  /left/wrist/acceleration [0. 1.]
  /left/wrist/position <x y z> [-1.5 1.5]
  /left/wrist/rotation [0. 1.]
  /left/muscle_activity [0. 1.]
  /right/shoulder/acceleration [0. 1.]
  /right/elbow/acceleration [0. 1.]
  /right/wrist/acceleration [0. 1.]
  /right/wrist/position <x y z> [-1.5 1.5]
  /right/wrist/rotation [0. 1.]
  /right/muscle_activity [0. 1.]
/quantity_of_motion [0. 1.]
/audio_video/record [0 1]
/annotations [0 9]

```



**Figure 26:** Screen shot of analysis patch with streaming annotations. The look-up table is displayed in the centre of the picture.

### 4.3 Results

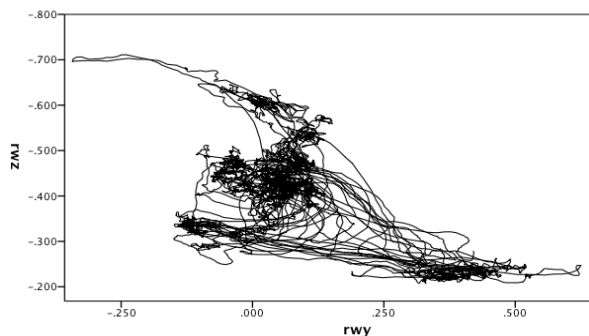
The files from the example presented here are found on the accompanying CD-ROM. The three different layers; raw, cooked and descriptive are recorded to separate files. These files are:

File Name	Description	Streams [columns×rows]
session3_recording1_impro-alone_raw.sdif	Raw layer: 4 streams	Accelerometer [3×9] Polhemus [2×6] EMG [2×1] AV-sync [1×1]
session3_recording1_impro-alone_cooked.sdif	Cooked layer: 5 streams	Accelerometer [1×9] Polhemus [2×4] EMG [2×1] AV-sync [1×1]
session3_recording1_impro-alone_descriptive.sdif	Descriptive (and functional) layer: 7 streams	Head [1×1] Neck [1×1] Back [1×1] Arms [2×8] Quantity of Motion [1×1] Annotations [1×1] AV-sync [1×1]

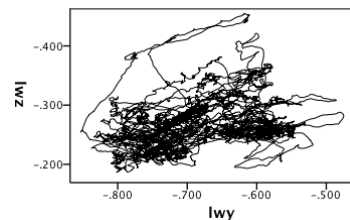
The acceleration values can be interpreted as indicators of movement. I assume that if an accelerometer stream has low values over a long time, there is little movement in the accelerometer, and conversely that any peak in accelerometer values indicates movement.<sup>49</sup>

<sup>49</sup> It is theoretically possible to achieve a low accelerometer value, with the accelerometer moving. The player would

The subject used the right hand for plucking the strings, for bending the plate, for adjusting the pickup switches and volume controls on the Nymophone2, and for adjusting the delay module. Looking at the position data from the right wrist, these four actions are identifiable as the most frequent positions for the right hand. This is shown in the plot in figure 27, where the YZ position coordinates of the right hand are plotted. Z position is upwards, and Y position is from left to right from the performer's perspective. X position is from the back to the front, and because X position varies less than the other two coordinates<sup>50</sup> I find it acceptable to leave the X-coordinate out of the

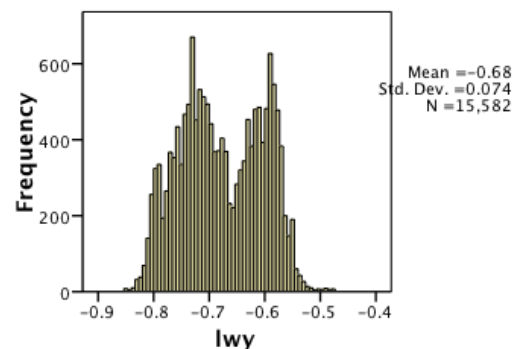


**Figure 27:** Right wrist Y/Z position  
(from the performer's perspective)



**Figure 28:** Left wrist YZ position  
(from the performer's perspective)

plot to make it a 2D plot which is easier to read than a 3D plot. The cluster on the lower right part of the figure displays the position for adjusting the delay module, the small cluster on the lower left part is the position of the volume controls on the Nymophone2; the large middle cluster on the left is the position for plucking strings and the small cluster above this is the plate bend position. The movement between these positions seem to be following similar trajectories.



**Figure 29:** Left wrist, Y-position coordinates

The left hand was used for shortening the strings with a slide and for bending the plate. The equivalent plot for the left hand (figure 28) shows a smaller range. The variation in both X and Z

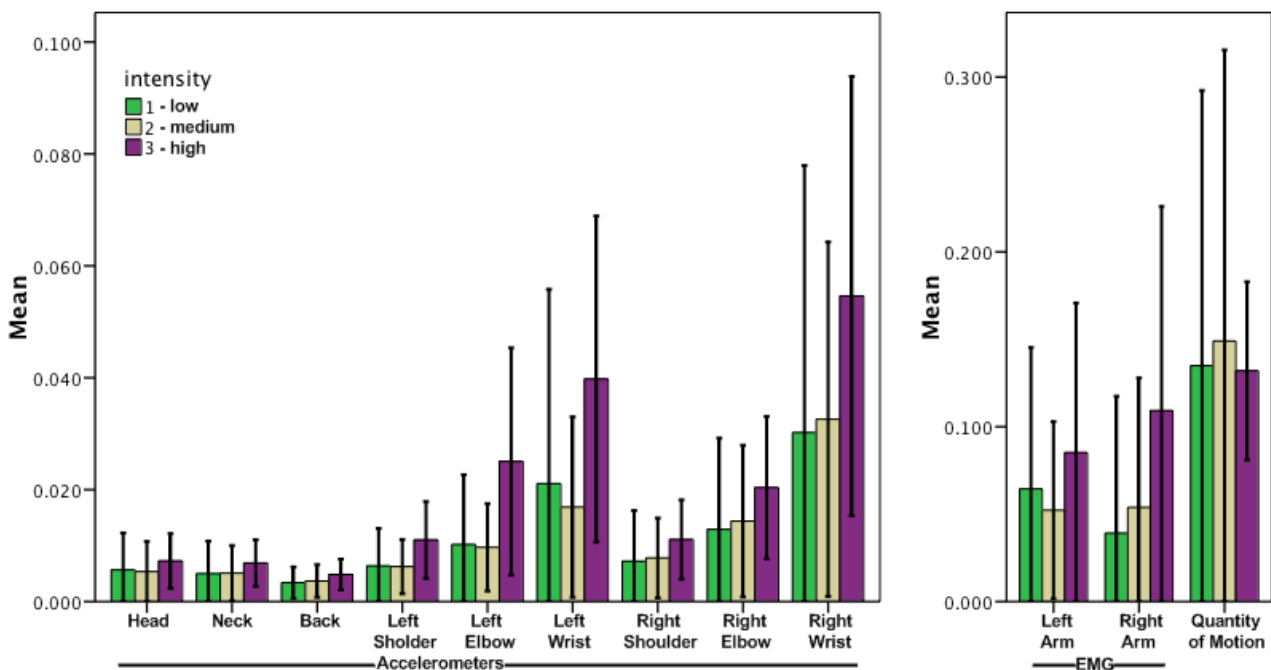
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have to keep the accelerometer from rotating, or constantly compensate for any rotation by accelerating the accelerometer in a certain direction. I have not calculated this mathematically, but assume that the probability of this happening over several samples is very small.

<sup>50</sup> I calculated the *standard deviation* of the position coordinates to get an indication of the “usual” positioning of the hand in the three directions. For the right hand position coordinates, X has standard deviation of 3.8 cm, Y of 16.3 cm and Z of 10.5 cm. This means that most of the recorded values were within a range of 3.8 cm from the mean value in the X direction, while for the Y and Z directions the variation in position is greater.

coordinates is quite small,<sup>51</sup> and the Y coordinate varies between two clusters, better displayed in the histogram in figure 29. The position clusters refer to what Cadoz and Wanderley (2000) call *posture*. Postures are start positions of an action, and according to Cadoz and Wanderley (ibid) “posture and gesture co-occur”, i.e. determining postures is part of examining the actions in a music performance.

I have looked at how the recorded sensor data change with the intensity of the performance, based on the intensity information in the GDIF annotation layer. Such a comparison can be interpreted in two ways. The first possible interpretation is “which of the recorded parameters are most affected by performance intensity?”. The intensity annotations were recoded as my subjective opinion, and thus another possible interpretation is; “what visual and auditive parameters influence the experienced intensity of a performance?”. The charts in figure 30 present the mean and the standard deviation of the acceleration values for the different body parts, the EMG for both arms, rotation of both wrists and quantity of motion. These three bars above each sensor display the three different intensity levels that were recorded to the annotation stream. Figure 30 shows that activity seems to



**Figure 30:** Mean and standard deviation of the recorded data. The standard deviation indicates the reliability of the mean values. These values are quite high, and thus the plot can not be basis for hard conclusions on the performance. The standard deviation is defined as the square root of the variance of a data set, and thus also indicates how much the data fluctuates.

increase in all the sensors when the intensity of the performance increases; the only thing that does not increase with intensity is the quantity of motion data from the video analysis. However, for the quantity of motion, there is a significant change in standard deviation. This is most likely due to that the subject did only play on the Nymphone2 (not on the delay module) during the high-intensity

<sup>51</sup> For the left hand position coordinates, X has standard deviation of 3.7 cm, Y of 7.4 cm and Z of 4.0 cm

periods, i.e. the movement was isolated to a smaller surface, hence generating smaller values for the quantity of motion analysis. Another possible explanation for this may be found by looking at the video for the 30 second high-intensity period in this performance from time 3:20 to 3:50 in the video file “Nymophone2 Performance.mov” in the “Video” folder on the accompanying CD-ROM. The performer is making constant, periodic movements, which generates less variance in the quantity of motion.

I find it interesting that the EMG values, especially the values for the right arm, are remarkably higher when the intensity is higher. The standard deviation for EMG on all three intensity levels is quite high, but there still seem to be a correspondence between perceived intensity and muscular activity. The most interesting aspect of this is that the EMG values are not directly visible to the person making the subjective judgements of intensity level. Thus, if the perceived intensity change is due to change in muscular activity, there must be some kind of intermediary between the muscular activity as reflected in the EMG data and the person making the judgement. In this case, it is natural to look at the activity of the right wrist, which to no surprise also seems to be increasing significantly with intensity level. Figure 30 also shows that activity of the whole left arm seem to follow the performance intensity. In particular, the activity of the left elbow is more than doubled in the highest intensity level compared to the two lower performance intensity levels.

#### ***4.4 Thoughts on the experiment***

I met several challenges during the presented experiment. Perhaps the greatest obstacle was the amount of data. Three sessions, each with three performance recordings between one and 6 minutes generated lots of data. In my analysis I have been using SPSS<sup>52</sup> on a Mac Pro, which should be capable of handling large amounts of data, but in spite of that, I have lost count of the number of crashes this amount of data has caused to the system. The problems related to the data management in addition to the poor sensor data in the two first recording sessions (as mentioned above), is the reason for that I have only focused on one of the recordings in this presentation. Another minor challenge needs to be mentioned in case the reader wants to look at the recordings that are included on the CD-ROM: I used the same Max/MSP patcher for recording video as the one being used in the previously mentioned research project at the University of Oslo. This patcher recorded the video to a slightly higher speed than the real timing. To get a perfect synchronisation, it is necessary to play back the video at 86% of the normal speed. This only counts for the video in the “Performance Experiment” folder on the CD-ROM.

By using the Polhemus tracking system, we may get an understanding of the positioning of

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<sup>52</sup> <http://www.spss.com/>



the performer during the performance. Position clusters may be correlated to sonic features or to the annotations. In my example, the position coordinates show four different postures for the right hand and two postures for the left hand; something which could have been extracted by subjectively adding annotations when viewing the actual performance or a recorded video; but plotting sensory data is a faster and more accurate method.

Evaluation of the setup could also be done by comparing GDIF annotations to sound descriptions, like the standard sound descriptions in the SDIF format. In my example, the GDIF annotation *bending plate* could be compared to the SDIF stream type 1FQ0, which contains data on the fundamental frequency of the sound. A strength of the GDIF approach, as shown in the experiment, is the possibility of adding annotations to the recordings, simplifying a comparison between sensor data in respect of subjective judgements of the performance.

I do not believe that the recordings and simple analysis I have presented in this chapter are sufficient for a description of playing technique. In particular, the control actions performed in these recordings were often done subsequently; e.g. first plucking (and shortening) string, then deforming the plate. It is likely that with more practice, more control actions would be performed simultaneously, to the extent possible in regard of human kinematics. This could enhance to what extent the performer could control several sound variables simultaneously. The recordings have, however, provided some good data, usable for quantitative analysis. Using position data it is possible to quantitatively compare the trajectories of the wrist movements and get deeper knowledge of the features of the actions in the playing technique. Applying the previously presented terminology of Schaeffer (1998), where *reduced listening* is used to investigate the *sonic object*, to the sound-producing actions in the form of Godøy's (2006b) previously presented *gestural-sonic object*, we may denote these recordings as *reduced observations* of the sound-producing actions. In this context, *reduced observation* would mean disregarding the everyday connotations of an action, focusing on different features of the action in order to achieve a deeper understanding of it.<sup>53</sup> I will address playing technique in more detail in the next chapter.

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53 See page 8 of this thesis for a comparison to Shaffer's use of the term *reduced listening*.

## Chapter 5: The Nymophone2 – musical construction and evaluation

This chapter presents the Nymophone2 from a traditional organological perspective, and an evaluation of the instrument from a performer's perspective, using the theory presented in chapter 2 and observations from the previous chapter.

### 5.1 Organology

In this section I will rather briefly present the Nymophone2 in light of the Hornbostel/Sachs system and Heyde's system for instrument classification which were presented in chapter 2. I will also discuss some problems regarding classification of the Nymophone2 in these systems.

In the system by Hornbostel and Sachs for classifying musical instruments, the Nymophone2 would be classified as an *electrophone*, in the subcategory *electromechanical instrument*. Electromechanical instruments are “based on vibrations produced in the usual mechanical ways and transformed into electric vibrations” (Sachs 1942: 467). Taking into account the small number of different electrical instruments at Sachs' time, one can understand the simplification being done by categorizing all electrical instruments as electrophones. The increasing variety in musical instruments that are based on electronics in one way or another, leads to a need for a further description than simply classifying the instrument as an electromechanical instrument. There is still no common consensus on how this should be done. Some call for a subdivision of the “electromechanical” class (Davies 1985), and others would want to remove this category and classify all instruments that use mechanical motion within the original four top categories; *membranophone*, *idiophone*, *chordophones* and *aerophones* (Montagu 1985). Thus, it is problematic to make a more detailed classification or description of the Nymophone2 in the Hornbostel/Sachs system. The handling of electronic instruments in traditional systems for instrument classification is one of the weaknesses that are pointed out by Kvifte (1989: 6, 122).

To make a description of the Nymophone2 using Heyde's system, I will start by presenting a diagram of the Nymophone2 using Heyde's symbols which were presented in chapter 2. The diagram is shown in figure 31. The *initiator*<sup>54</sup> in this system is the muscular system in the right arm. The performer has control over the *energy state*, i.e. whether the muscle contracts or not, and the *energy amount* displayed in two *control elements* connected to the right arm muscle. The energy from the muscle is applied to the *transformers* (strings) through the right hand and fingers by plucking the strings. *Energy state* and *energy amount control* are also the *control elements* that apply to the left hand. The left hand and the slide (if a slide is being used) are *setting elements* controlling

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54 To distinguish between my own presentation and Heyde's (1975) terms, all of Heyde's terms are displayed in *italics*.

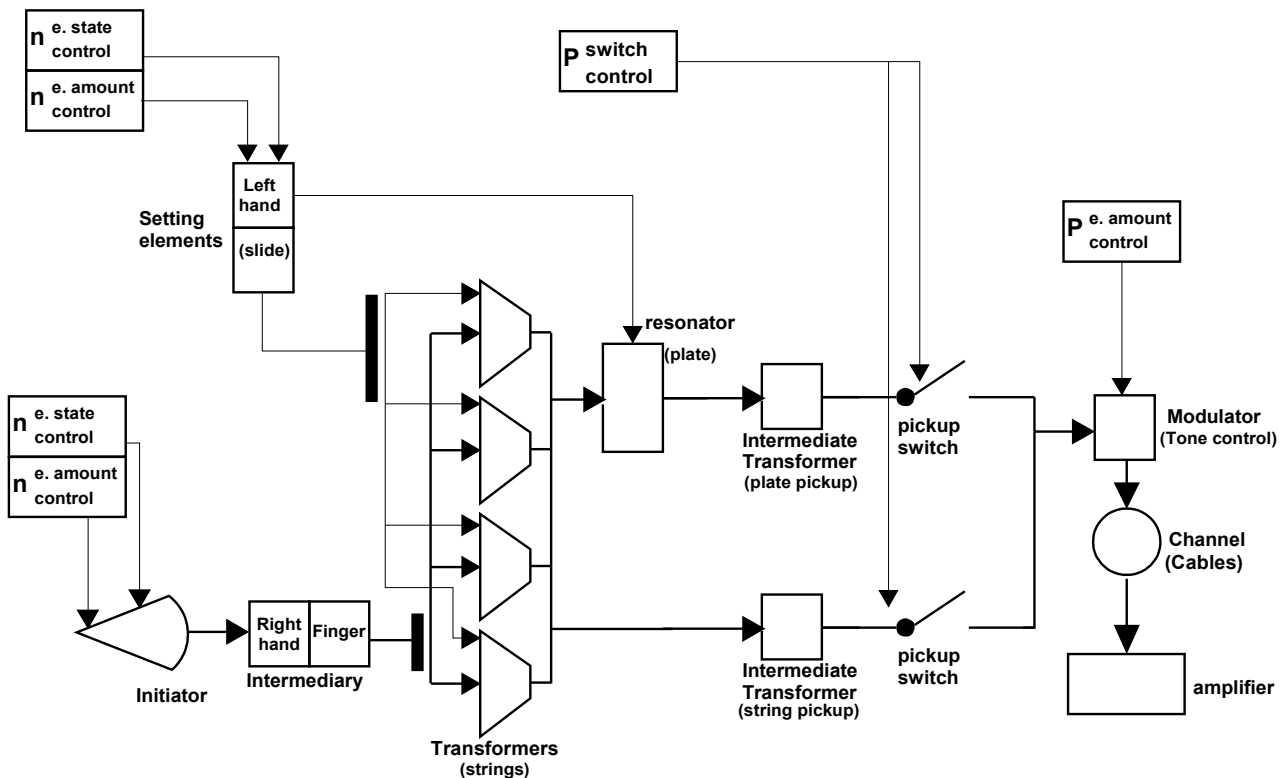


Figure 31: Description of the Nymphone2 using Heyde's system.

the strings. Both hands can be *setting elements* controlling a *resonator* (the plate). In the figure, I chose to only display this for the left hand, because the right hand already was displayed as an *intermediary*, and to label it a *setting element* as well would only make the diagram more confusing.<sup>55</sup> The energy passes from the plate and the strings to the *intermediate transformers*, which both may be switched on or off, and the tone control, which in Heyde's terms is a *modulator*. The *switches* and the tone control are mechanical, and are thus controlled by *Programmesteuerung*.

There are some problems related to using Heyde's diagrams. First of all, the control actions are somewhat undefined, e.g. the diagram shows that the performer's control over the *initiator* is *energy amount control* and *energy state control*, but the diagram does not say in what way the two control types affect the sound coming from the instrument. The second, and perhaps the most significant shortcoming of Heyde's diagrams when describing the Nymphone2, is the linearly ordered structure of these diagrams. This problem does not emerge with the Nymphone2, but is relevant to a certain extent to many instruments. As Kvifte (1989: 48) points out, Heyde uses an unfortunate example when he denotes the bridge of a string instrument as a *channel*, which is a passive carrier of information. The bridge does indeed influence the instrument's sound, and transfers energy not only from the strings to the resonating body, but it vibrates in itself, thus transferring energy between the strings (Jansson 2004). The phenomenon of energy being transferred between the

<sup>55</sup> As far as I see, Heyde does not mention the possibility of a hand acting as both an intermediary and a setting element simultaneously.

strings is probably not a main concern to most string instrument players, as it is not a phenomenon that they control using the traditional control organs of the instrument. Thus, even though Heyde's system seems to be more from the perspective of instrument constructor than that of the performer, one could possibly argue that this is not a big problem in most traditional instruments. However, in the Nymphone2 the four strings and the plate affect each other to such an extent that a linear view of the system is insufficient. In my belief, Heyde's system, expanded with clearly defined functions of the *control elements*, as well as an expansion to describe non-linear interaction between the elements of the instrument would be a good way of describing instruments from the instrument constructor's perspective.

Traditional systems for describing musical instruments aim to give a full description of the whole system that make up the musical instrument. This is especially evident in Heyde's system, when he allows the limbs of the performer to be described as *anthropomorph* parts of the instrument. Although the Hornbostel/Sachs system is not completely defined for *electrophones*, one can imagine the system classifying the Nymphone2 differently if it is connected to an amplifier with one speaker or an amplifier with two speakers. The system seems to have unlimited possibilities for classification into subcategories, which is a challenge when the instrument can be expanded by an unlimited number of different effect modules and amplifiers.

I believe that for certain instruments it is beneficial to divide the description into several separate *modules*, as Kvifte does when addressing electronic musical instruments (Kvifte 1989: 122). For a synthesizer the term *sound module* is commonly used when referring to the sound generating part of the instrument. Kvifte (ibid.) also separates the control organs used for playing from the *instrument definition controls*, which are control organs defining the mappings between other control organs and musical parameters. In my opinion it must be valid to describe a modular unit which is part of an instrument, rather than having to describe the whole instrument in use. In one sense, this is what Heyde does in his system. This system however, is in my opinion too detailed to be interesting from a performer's point of view. Heyde's perspective can thus be seen as both a micro-perspective, i.e. the detailed modular separation between instrument parts, and a macro-perspective, i.e. a description of the whole instrument. To describe a module from the perspective of the performer I call for mid-level modular distinctions. Such modules may either depend on, or be independent of, other modules to function as a musical instrument. It is not my intention to regard modular units any less worth than "complete" musical instruments. The separation is merely to simplify instrument classification.

## 5.2 Playing Technique

I find Kvifte's system for description of playing technique to be a good starting point for a comprehensive description of the playing technique associated with the Nymophone2. Kvifte's system is a very general model, which is meant as a system for describing playing technique for any instrument. Because my presentation is only concerned with one specific instrument, I find it necessary to go deeper into the description than Kvifte does in the examples in his book. I mainly focus on the Nymophone2 in itself, but would like to point out that in the presentations in this section it is implicit that the Nymophone2 is plugged into an amplifier.

Kvifte denotes a musical instrument in its fundamental meaning as “an instrument which is used to make music” (Kvifte 1989: 62), and also as “the tool of playing technique” (ibid. 10). Defining a musical instrument by it having a playing technique excludes some objects from being incorrectly defined as musical instruments, e.g. the pen of the composer writing a musical score. The meaning of the term *playing technique* depends on the context within which it is used, but in the common understanding of the term *playing technique* means “what performers do with their instruments to accomplish desired musical results” (ibid: 60). To the performer, *playing technique* has the role of being a way of transforming a musical idea to a sound. To the perceiver it takes on the role of being communicative, i.e. a visualisation of the musical utterances made by the performer. Kvifte emphasises that playing technique should be described from the performer's point of view (ibid: 64). This point of view exists in the context of a performance, where the control actions, the control organs, and the feedback from the instrument, are the interesting features that should be described.

### *Control actions and control organs of the Nymophone2*

Although I have already mentioned all of the control organs and the control actions for the Nymophone2, I would like to start my description of playing technique on the Nymophone2 with an overview of these.

Table 3 presents an overview of the control organs and control actions for the instrument. This table is an attempt to make a complete overview of possibilities, with the exception of actions concerning the wooden frame and actions that would require deforming the instrument or use of external tools not initially intended for the instrument.<sup>56</sup>

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<sup>56</sup> For instance, the method of exciting the plate or the strings by electricity, magnetism or variations in air pressure.

Control Organ	Control Actions
4 Strings	Excitation (Plucking, Bowing, etc.) Pulling Shortening Damping
Plate	Excitation Damping Deforming
Pickup Switch (2)	Switching on/off
Volume Controls (2)	Turning up/down
Tone Control	Turning up/down

**Table 3:** Control organs and control actions for the Nymophone2. Any other control action is a combination of the actions presented in this table. For instance, the control action of crossing two strings is pulling two strings across each other for the reason of shortening and damping one string with the other.

In order to not to have to be too detailed in the further description of playing technique, only what I find to be the most interesting selection of actions presented table 3 is discussed in the remainder of this chapter. I will look further into string excitation, pulling, shortening and damping, as well as plate damping and deforming.

All the strings and the plate of the Nymophone2 are more or less affected when any control action is performed on either one of the strings or on the plate. The way each of these components is affected depends mostly on whether the component is put into motion directly, e.g. by plucking the string, or indirectly, e.g. by plucking another string than the string in question. It is therefore necessary to describe the components both as the *primary vibrating material*, and as *resonators* to a vibration in the other components. I will not focus this discussion on the details of the interplay between the strings and the plate, but feel the need to discuss some of this complexity. If one string is excited the plate will resonate, particularly so due to the string being directly connected to the plate. The other strings will also resonate due to the connection between the plate and these strings. Because the plate is not fixed in both ends, the tension of all the strings will vary when the plate is vibrating; thus neither the pitch of the plucked string nor the timbre resulting from the resonance in the plate and the other strings will be constant. Damping, shortening or pulling of one of the strings will not only affect the string itself, but also the plate resonance and the other strings. However, not all of these aspects seem to be perceptually prominent, thus I will keep focus on the most prominent effects on the musical parameters when describing playing technique.

It is necessary to address the hierarchy of the Nymophone2 control actions, as certain actions determine the *domain* of other actions (Kvifte 1989: 116). Considering the musical parameter *pitch*, the choice of which string to excite is at the top level, determining the *range* of all the other control actions for pitch. At the next level is the vibrating length of the string in question, i.e. the action parameter *position* of the control action *shortening the string*. Damping the string is third

in the hierarchy of pitch control. If the string is damped in a certain position a flageolet, i.e. harmonic of the string is heard. Subordinate to these three levels are the actions of deforming the plate and pulling the strings.

For the musical parameter loudness, the only hierarchical order of control actions is found when considering the electronic system,<sup>57</sup> all other control actions for loudness are non-hierarchical. Timbre can not be ordered into a one-dimensional hierarchy. Thus it is not meaningful to talk about hierarchical ordering of the control actions for timbre. For the control actions for timbre it is more meaningful to talk about domain selection. For example selecting to pluck the string with a plectrum gives another timbre domain than selecting to bow the string.

As mentioned in chapter 2, I believe that describing the sound producing actions by themselves is not a satisfactory description of control actions for the instrument. The actions should be described in terms of the *action parameters*, i.e. the *features* of the actions that are relevant for change in a musical parameter. Kvifte (1989: 89ff) does this starting with a musical parameter, e.g. *digital pitch*, and presents different control actions and some action parameters for controlling the musical parameters. In my opinion, such a description is best done by starting by describing the action parameters in terms of their relation to the control organs. When the action parameters are defined, the way these parameters are coupled and organized in levels, may be put in relation to the musical parameters that they control.

Table 4 contains an overview of the action parameters of most of the control parameters relating to the strings and the plate. Plucking the string is a continuous action in terms of the accentuation and the plucking position and angle. Choice of medium used for plucking and which string to pluck are discrete variables. The action parameter accentuation is mapped to loudness, and it is also mapped to the envelopes of timbre and pitch. When considering the action parameters for damping the string, it is necessary to know whether the string being damped is the originally excited string or a resonating string. A string which vibrates only as a result of another string vibrating has so little energy that the control action of damping the string is a discrete choice between damping or not damping. Damping this resonance string does not affect the primary vibration much, and this action can therefore be denoted as a discrete action for timbre. For the string being excited e.g. by plucking, two types of action parameters become relevant. Timbre is controlled by the discrete choice of medium used for damping the string, e.g. a finger or a plectrum, and by continuous position and area of the damping. The latter action parameter is also relevant to continuous loudness, as well as discrete pitch (flageolets). Similar consideration may be done for the other action parameters.

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<sup>57</sup> For instance, turning up the amplifier could be seen as a top level control action for loudness.

Control Organ	Control Action	Action Parameter	Parameter Type	Mapped to
String	Plucking	Choice of string	Discrete	Pitch
		Accentuation	Continuous	Timbre, Loudness, Pitch
		Position and angle	Continuous	Timbre
		Medium	Discrete	Timbre
	Shortening	Position	Continuous	Pitch
		Medium	Discrete	Timbre, Loudness
	Pulling	Force	Continuous	Pitch, Timbre
	Damping	Position and area	Continuous	Timbre, Loudness, Pitch
		Medium	Discrete	Timbre, Loudness
Plate	Damping	Position and area	Continuous	Timbre, Loudness
		Medium	Discrete	Timbre, Loudness
	Deforming	Force	Continuous	Pitch, Timbre
		Position and direction	Continuous	Pitch, Timbre

**Table 4:** Action parameters for the Nymophone2

When the action parameters are defined, the multidimensional mapping may be examined. Using Kvifte's model for a schematic overview of couplings (Kvifte 1989: 102ff), we find that all of the musical parameters are subject to control couplings, and more than half of the control variables control more than one musical parameter, as displayed in table 5.

	Pitch		Loudness		Timbre	
	C	D	C	D	C	D
Exciting string – choice of string		<input type="checkbox"/>				
Exciting string – Accentuation	<input type="checkbox"/>		<input type="checkbox"/>		<input type="checkbox"/>	
Exciting string – position and direction					<input type="checkbox"/>	
Exciting string – medium						<input type="checkbox"/>
Shortening excited string – position	<input type="checkbox"/>	<input type="checkbox"/>				<input type="checkbox"/>
Shortening excited string – medium				<input type="checkbox"/>		<input type="checkbox"/>
Pulling excited string – force	<input type="checkbox"/>	<input type="checkbox"/>			<input type="checkbox"/>	<input type="checkbox"/>
Damping excited string – medium						<input type="checkbox"/>
Damping excited string – position and area		<input type="checkbox"/>	<input type="checkbox"/>		<input type="checkbox"/>	<input type="checkbox"/>
Pulling resonating string – force	<input type="checkbox"/>	<input type="checkbox"/>			<input type="checkbox"/>	<input type="checkbox"/>
Damping resonating string						<input type="checkbox"/>
Deforming plate – force and direction	<input type="checkbox"/>	<input type="checkbox"/>			<input type="checkbox"/>	<input type="checkbox"/>
Damping plate – position and area			<input type="checkbox"/>		<input type="checkbox"/>	<input type="checkbox"/>
	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

**Table 5:** Couplings in Nymophone2 instrument control. Using system from (Kvifte 1989). C denotes continuous control of a sound variable, D denotes discrete control of a sound variable. Several of the parameters for pitch control are both continuous and discrete, as they are continuous and have a range large enough to adjust pitch between several discrete perceptual categories (tones). For a discussion of this, see (Kvifte 1989: 101) and (Kvifte and Jensenius 2006).

My final consideration for playing technique using Kvifte's system is the possibilities for control of the sound after the initial attack. As explained in chapter 2, my interpretation of Kvifte's system is that the variables may be adjusted and reversed to the original state after the initial attack. None of the instruments with a decaying tone in Kvifte's table can be controlled in terms of more than one musical parameter after the attack. On several of the instruments, pitch may be controlled



by adjusting the tension of a string or a membrane, and the jew's harp is presented as an example where the loudness may be controlled. In this aspect, the Nymophone2 seems to expand the control possibilities of instruments with decaying tones. By adjusting the plate and the strings, the performer has control over both timbre and pitch of the decaying tone.

After this overview of the control possibilities and couplings in the instrument, we may consider more advanced features of the complex control mappings. The multidimensional control surface the plate represents is complex, too much so for a complete overview of the control possibilities. But I will look into some examples where only the control action of deforming the plate is used to control several tones individually.

As a practical example, using standard terms from tonality of western music, consider the situation of putting the A and C# strings into motion, the major third interval may be experienced as tonic chord (A). It is possible to make this tonic chord into a dominant chord in several ways. I will present three examples:

1. By pushing down the two corners of the plate that are closest to the performer and at the same time pushing the plate upwards at a point between the two corners, using a certain force, the tone A shifts up a whole tone to a B<sup>58</sup>, and the C# shifts up half a tone to a D. These two tones are the fifth and the seventh tone of an E7 chord.
2. The tones can also be turned into a B and C# by pressing two opposing corners of the plate. This way the resonance of the plate is adjusted differently than in the first example.
3. By pressing the plate down with the right force about mid-way along the string and about 8 cm from the edge of the plate, the two tones shift down to F# and B, which are the fifth and ninth tone of an E9 chord.

Besides the examples above, there are several ways of deforming the plate to make the two tones shift to the same tones as in the examples. These examples are of course simplified to a focus on pitch: one could look at the loudness of the tones and details of timbre of the sound.

### **5.3 Psychoacoustic Considerations**

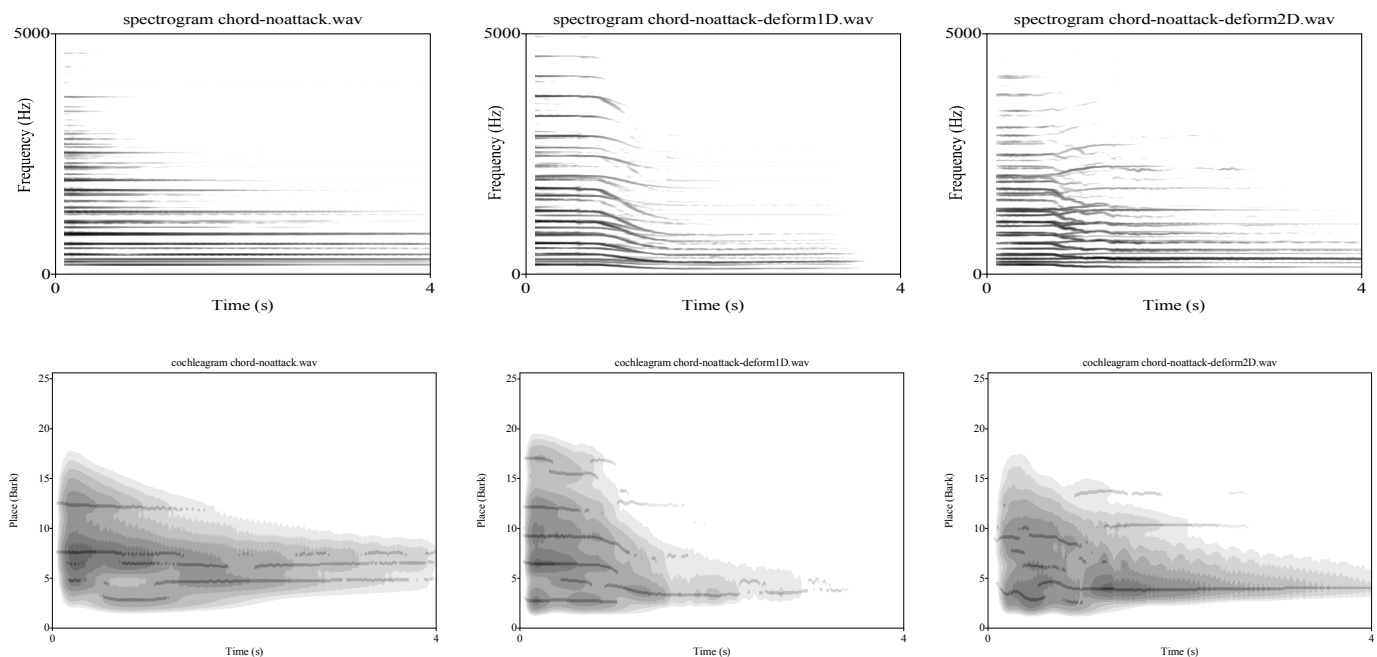
The sound from the instrument is important as feedback to the performer. It is therefore interesting to look at some of the psychoacoustic aspects of the Nymophone2 sound. I will look into what we actually hear compared to physical analysis like the spectrograms used in chapter 3, and I will investigate what happens in our perception when the plate is deformed. To make these evaluations, I

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58 In Norwegian, this is the tone H

use *cochleagrams* from *Praat*. Cochleagrams show the excitation pattern of the basilar membrane in the inner ear, and give indications on how different parts of the frequency spectrum are masked. I will also question our mental processing of the instrument sound; do we hear the sound from the instrument as a unity which can not be separated into smaller mental images, or do we hear concepts like string, metal, plate, square and pluck?

The complexity in control and sound leads to difficulties both in controlling and categorizing the sound from the instrument. One example is the phenomenon happening when all the strings



**Figure 32:** Cochleagrams of chord sound from Nymphone2. Left: No deforming of the plate (“Figure32a.wav”), Middle: Deforming the plate in one dimension (“Figure32b.wav”), Right: Deforming the plate in two dimensions (“Figure32c.wav”) are put into motion and the plate is deformed in such a way that the pitch of some of the stings are

raised, while for some it is lowered. Three spectrograms and cochleagrams of some Nymphone2 chord sounds are displayed in figure 32. Note, in the lower right plot, how the basilar membrane excitation patters abruptly changes when the plate is deformed in two dimensions simultaneously. For the chord sound that is allowed to ring out without deforming the plate and for the sound when deforming the plate in only one dimension, the basilar membrane excitation patterns are more homogeneous along the whole span of the sound, mirroring the actual frequency components of the sounds that are shown in the spectrograms. Applying Pierre Schaeffer's (1998) previously presented typology for the *tonal mass* of the sonic object to the sound from the nymphone when the plate is multidimensionally deformed, such a sound would be a hybrid between the three main categories. First, it is an object of *tonal mass* due to the easily interpreted four tone harmony, i.e. an A major seven chord when the strings are open. Second, the act of altering the pitches of the strings causes it to be an object of *varying mass*.<sup>59</sup> Third, as shown in the cochleagram in figure 32, the pitches of a

<sup>59</sup> As presented in chapter 2, varying pitch is Schaeffer's definition of an sonic object of *varying mass*.

deformed plate are not easily perceived, thus we have an object of *complex mass*, which is Schaeffer's term for a sonic object without a distinct pitch.

I have evaluated the acoustic analysis of the plate using an analysis-by-synthesis approach. The synthesis model used was a very simple formant synthesis based on subtractive synthesis.<sup>60</sup> In my synthesis the waveform of a synthetic string sound was passed through a formant filter, i.e. a set of 12 peak filters where each of the filters referred to one of the plate resonances in table 1 (page 37). The audio files are analysed using cochleagrams in figure 33, I will look into the cochleagrams shortly, but mention this now to make the reader aware that the audio files are available on the CD-ROM, named "Figure33a.aiff" and "Figure33b.aiff" (details are presented below). The sound from a "perfect" string has harmonics at  $n \times f_0$ , where  $f_0$  is the fundamental frequency, and  $n$  is any positive integer. The amplitudes of the harmonics decrease when  $n$  increases, and the relationship between these amplitudes depend on the plucking position. In my experiment, I used a Steinberg A1 VST synthesizer to synthesize a string sound with a fundamental frequency of 220 Hz. I did not find the initial synthesized sound to be very similar to a string sound, it was too harmonically rich. Hence I processed the sound to attenuate the higher partials, making a more mellow sound that in my opinion was closer to the sound of a string.

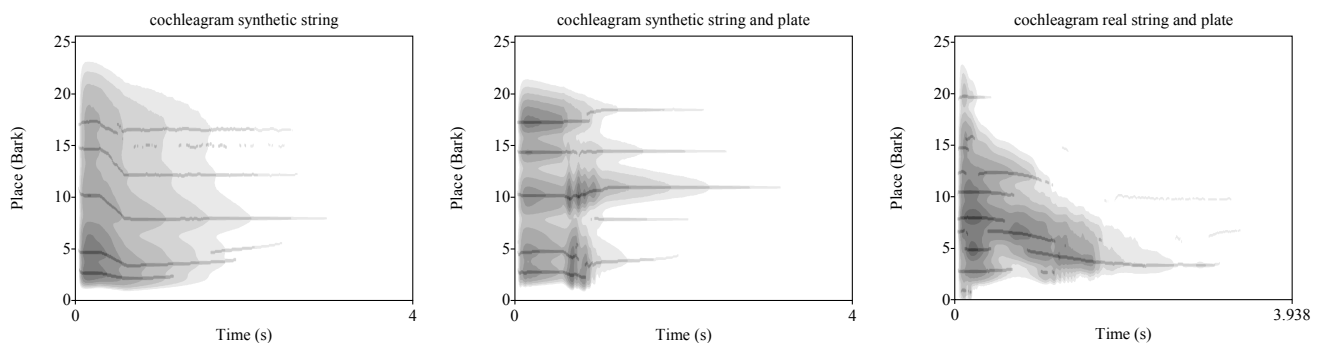
I used a Phidgets force sensor as a simple user interface for simulating bending of the plate in one dimension (along the strings, the same dimension as in table 1). When no force is applied to the sensor, the resonant frequencies of the filters are like the plate resonances in the equilibrium state, and the string sound is played with its original pitch. When the force sensor outputs its maximum value, the filter resonances are as the plate in the bent state in table 1 and the string sound is played back at 0.7 times the normal speed, lowering the frequency to 154 Hz which is an approximation of the pitch change when bending the plate with the force I used in the previous measurements. The values in between the two extremes are ramped with linear interpolation. Due to the simplicity of the model, the synthesized sound does not sound quite like the Nymphone2, but it is much closer than the string sound was before it was passed through the formant filter.

I have compared a cochleagram analysis of the sound from this model to a cochleagram analysis of the same action being done on the instrument. These cochleagrams are displayed in figure 33. At first glance, the cochleagrams show that my model does not model the actual instrument very well. I do not have any way of recording the sound from the "real" Nymphone2 string without the plate; but I find it reasonable to believe that the "raw" synthesized string sound is not very close to what this "real" string sound would be. Thus, when considering that the raw input to the format synthesis may be considerably different from the actual string sound, a second consideration of the

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60 as is suggested in (Roads 1995: 299) as one of several possible methods for formant synthesis

cochleagrams in figure 33 give some clues of how the plate resonances manifest in the perception of the “real” sound. First, considering the attack part of the sound, it is clear that the formant synthesis causes a higher level of excitation in the higher critical bands of our hearing system than in the raw synthesized sound. Second, the model induces masking of certain frequency components when simulating deformation of the plate. This masking is also found in the real sound, shown in the rightmost plot, and in the plots of figure 32. The third aspect shown in the figure is that the model of plate resonance induce rise in excitations in certain parts of the basilar membrane during the decay of the sound. This is also shown in the rightmost plot of figure 33 and in the plots in figure 32.



**Figure 33:** 3 cochleagrams of sound from lowering string pitch. Left: Synthetic string (Figure33a.aiff), Middle: Synthetic string with plate model (Figure33b.aiff), Right: "Real" sound (Figure33c.wav)

Even though the synthesized sound is closer to the sound of the instrument than the original synthesized string sound, the sound is not close enough to the original sound to be identified as a Nymphone2 sound. For most instruments one is familiar with it seems that based on the auditory input alone it is rather easy to identify the instrument from which the sound originated. For instance, it is fairly easy to recognize a tone from a piano even though the sound from a piano has several different features along the range of tones. Pierre Schaeffer discusses several differences in low and high piano tones (Schaeffer 1998: 47ff). For instance, a low pitched piano tone is perceptually unaffected by removing the attack-part of the sound, while the same experiment for a high pitched tone gives a significant change in the way we hear the sound.

There seem to be some sort of collective features to the sound of an instrument, which are not based on a single extractable phenomenon like the spectrum of overtones or the loudness envelope, but a combination of cues that lead us to think of this instrument when hearing the sound of it.<sup>61</sup> For the Nymphone2, a small investigation of possible cues for this identification of the instrument by the sound alone could be done by looking at the Nymphone2 sound from an analysis by synthesis approach, evaluating strengths and weaknesses of methods like for instance the one presented above. However, I believe that clues for identification of an instrument through auditory clues can not be done by sound analysis alone. As argued by Godøy (2003) there are strong connec-

<sup>61</sup> Thanks to prof. Rolf Inge Godøy for presenting thoughts on this.

tions between mimicry of a motion features, e.g. *motor mimesis*, and sound perception. For the Nymphone2, the metal plate is not only a prominent feature in terms of acoustics, but also a prominent visual feature, thus I believe that an investigation of auditory features relating to concepts of *plates* and *metal*, as well as *square* and *bent* could be of interest. Such an investigation could possibly answer the following question: How did I know when I first started making the instrument, that this combination of a flexible plate and strings would bring out a “new” sound?

Structuring such clues is a demanding task. David Wessel (1979) presents a system for hierarchical organization of perceptual cues, applied to an empirical study of timbre. The basis of the system is that perceptual judgements are relative, e.g. one feature value is judged as closer to one reference feature value than to another reference feature value. Thus, based on empirical studies, he argues that one may find systems for ordering such clues. He emphasises that the hierarchy should not be a basis for quantitative comparisons, but for qualitative comparisons between sounds, and that a two-dimensional system seems to be sufficient for ordering some prominent timbral features of sounds. The sounds in Wessel's experiment are all sounds with a distinct pitch, and with continuous sound excitation. The two dimensions used for hierarchically ordering the timbral quality of sounds are *brightness*, represented by the spectral energy distribution of the tones, and *bite*, represented by the attack rate (Wessel 1979). A similar approach could possibly be taken for judging perceptual aspects of more abstract variables like shape or material. An example being a study by B. Giordano showing that the sound of freely resonating struck steel plates is often confused with the sound of a glass plate, while it is quite perceptually different from the sounds of plastic or wooden plates (Giordano 2003). Glass and steel plates were often both categorized as glass when the plates were small, and as metal when the plates were large (plates used were between 75 and 1200 cm<sup>2</sup>). Perceived fundamental frequency and decay time were the two most important parameters for categorizing the material producing the sound. The values of these parameters rely on physical properties of the material (ibid).

Perhaps empirical studies on sound will eventually lead to a multidimensional organization of objects, be that Shaffer's *sonic object*, Godøy's *gestural-sonic object* or Rocchesso/Fontana's *sounding object*<sup>62</sup>, which again may be applied to research on human capabilities of recognizing instruments by their sound. There are several prerequisites that would need to be fulfilled before this could be possible: In addition to classifying sounds by physical aspects like construction material, the multimodality of perception calls for auditory input to be compared to visual aspects like size and shape (Godøy 1997), motor-cognitive aspects like sound producing actions (Godøy 2006b), and tactile aspects like texture or friction (Sinclair and Wanderley 2007).

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62 (Schaeffer 1998), (Godøy 2006b), (Rocchesso and Fontana ed. 2003)

## Chapter 6: Conclusions

I am satisfied with the development of the Nymphone2. From starting as a vague idea and a hope of finding a “new” sound, I believe that I have managed to reach that goal. The instrument has certain similarities to some other musical instruments, but at the same time it greatly diverges from all the instruments I know of.

As I have little education in aesthetics, I am not qualified to make an academic aesthetic evaluation of the Nymphone sound. According to my own musical preferences, I am satisfied with the sounding result. The undefined pitch and harmony in the sound of a full chord when the plate is deformed in multiple dimensions suits my intentions of a new sound, and my fascination of timbre, well. I may develop the instrument further, investigating possibilities like a more defined tuning of the plate resonances, and flexible pickup placements. The instrument does certainly not look as pretty as most musical instruments. I have not focused on visual aspects in the development process, but the visual features of the Nymphone are potential areas of improvement.

In the process of describing playing technique, I have developed a critical view of some of the general musical parameters used by Kvifte (1989). In particular, the term *duration* stands out as problematic, because short durations may significantly change the way we hear sound. For instance, I do not believe it is obvious that alternating change in another musical parameter may be described in terms of the changing musical parameter and duration alone. I believe there are large perceptual differences between a sound fast alternating in pitch (i.e. vibrato) and slower alternations of pitch (i.e. melodic glissandi). A complete discussion of these terms would require a more detailed description of features of our perception than what I have allowed in this thesis. It would also require an extensive discussion of alternative terminology, which is beyond the scope of this thesis. The reader may have noticed that I left the musical parameter out of the discussion of playing technique (as Kvifte (ibid) also partly does) for this reason.

I have illustrated that the concept of complex multidimensional control is not necessarily just many-to-many mappings in the understanding that many actions being mapped to many musical features. When studying a *sonic object* through Schaeffer's (1998) *reduced listening*, we find multidimensionality within the musical feature *timbre*, and by studying Godøy's (2006b) *gestural-sonic object* in through a similar *reduced observation*, we may find multidimensionality in a single sound producing action through related movement like *postures* and *ancillary movement*, and through action parameters like *position*, *force* and *accentuation*. Thus, the important many-to-many mappings of human interaction with a musical instrument is just as much mapping between multidimensional objects as it is multidimensional mapping between objects.

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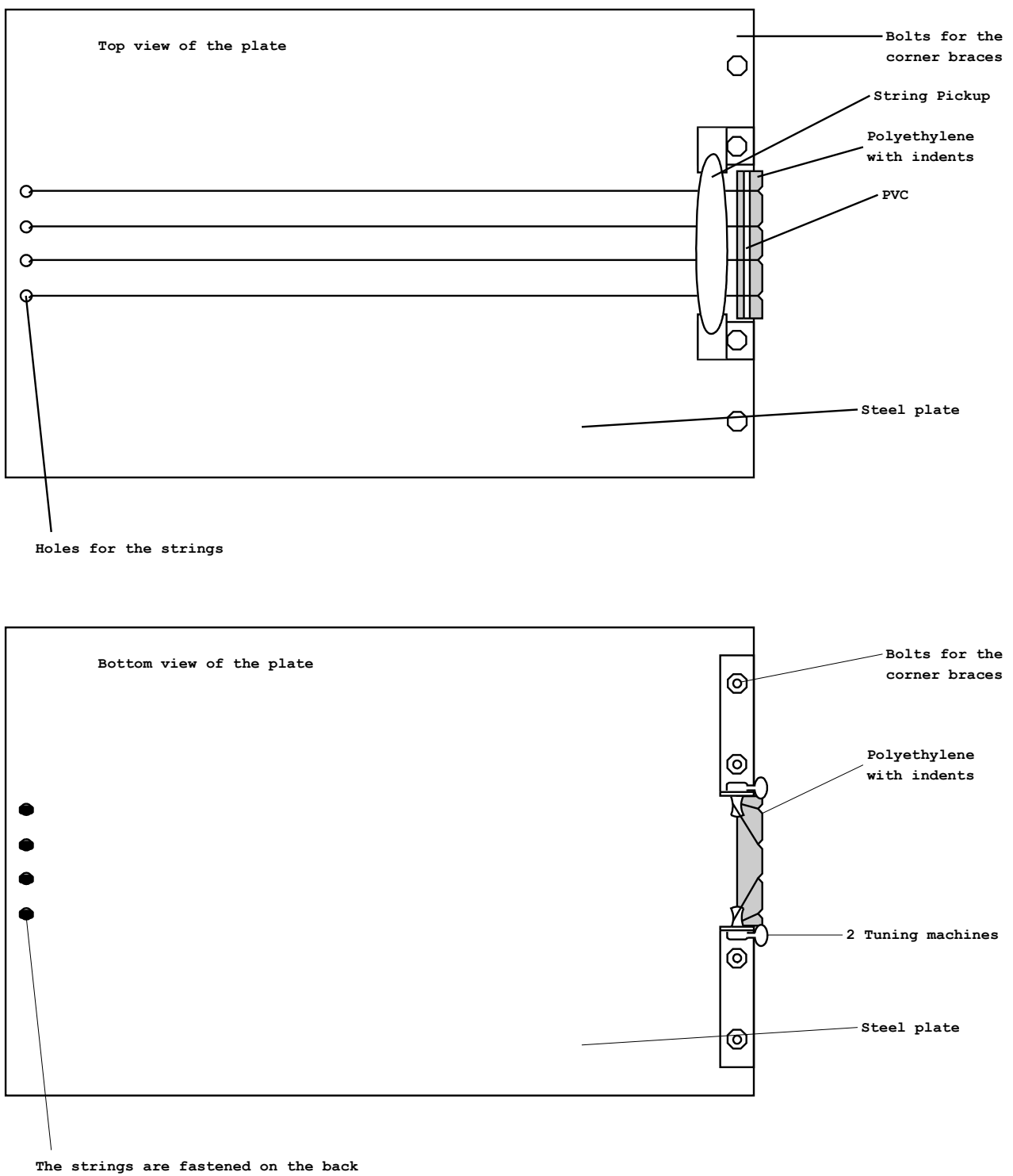


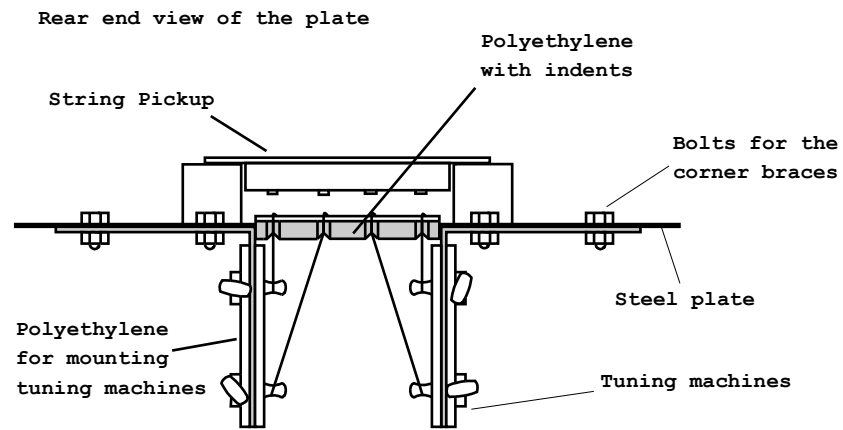
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Appendix

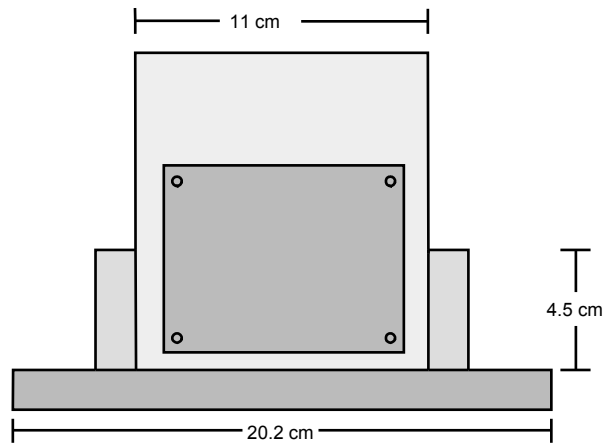
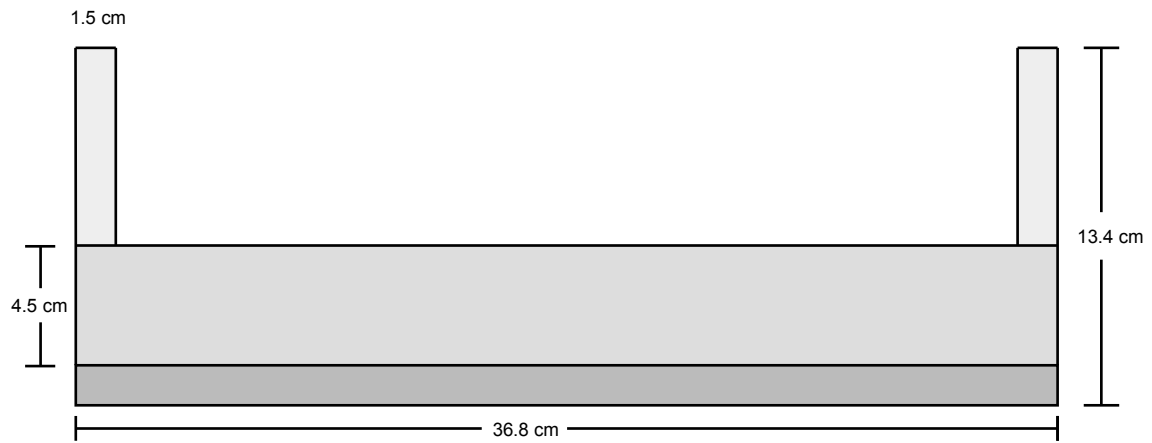
A. Figures

A1. Plate, strings and tuning system

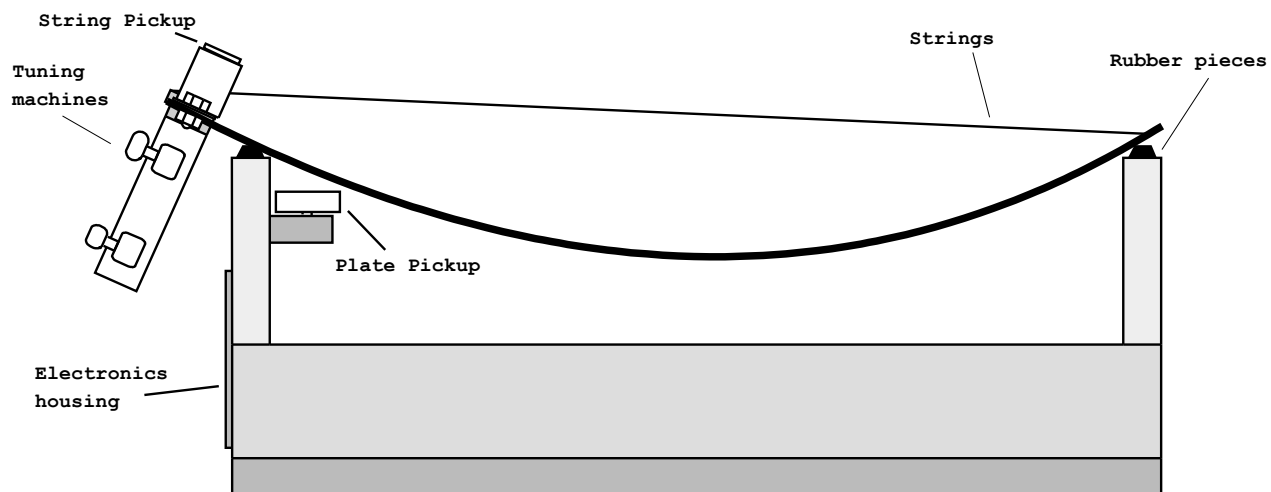




## A2. Frame



Side view of the nymophone2



## ***B. List of contents on accompanying CD-ROM***

### ***B1. Audio files***

Two folders contain only audio files. The “Audio Files - Figures” folder contains the sound files relating to the figures in the thesis. The “Audio Files - Plate Resonance” folder contains the files used for extracting the plate resonances (Table 1 on page 37). Some of the files in the two audio folders represent the same recording, e.g. the file “plate\_hit\_1\_noattack.wav” in the “Audio Files - Plate Resonance” folder is the same file as the files “Figure16a.wav” and “Figure17.wav” in the “Audio Files - Figures” folder.

Audio Files - Figures folder:

- Figure16a.wav      Resonating bowed plate (174 Hz)
- Figure16b.wav      Resonating bowed plate (395 Hz)
- Figure17.wav        Plate hit with mallet, attack removed
- Figure18a.wav      Plate hit with mallet, attack removed
- Figure18b.wav      Deformed plate hit with mallet, attack removed
- Figure19.wav        Plate being excited lightly with a bow. The plate is gradually deformed during the sound.
- Figure20.wav        All strings plucked and gradually shortened with a slide. The plate resonates when the string partials are close to the plate resonances
- Figure21.wav        Highly accentuated plucking of the Nymophone2 A-string
- Figure22a.wav        Lightly bowed plate, dismantled from the frame
- Figure22b.wav        Lightly bowed plate, attached to the frame
- Figure32a.wav        A major seven chord (four open strings). Attack removed.
- Figure32b.wav        A major seven chord (four open strings). Attack removed. Plate deformed in one dimension
- Figure32c.wav        A major seven chord (four open strings). Attack removed. Plate deformed in two dimensions
- Figure33a.aiff        Synthetic string sound
- Figure33b.aiff        Synthetic string sound and plate model
- Figure33c.wav        “Real” equivalent to Figure33b

Audio Files - Plate Resonance folder:

- plate\_hit\_1\_noattack.wav
- plate\_hit\_1b\_noattack.wav
- plate\_bow\_1.wav
- plate\_bow\_1b.wav
- plate\_bow\_3.wav
- plate\_bow\_3b.wav
- plate\_bow\_5.wav
- plate\_bow\_5b.wav
- plate\_bow\_6.wav
- plate\_bow\_7.wav
- plate\_bow\_7b.wav
- plate\_bow\_8.wav
- plate\_bow\_8b.wav
- plate\_bownoise\_sb.wav

## ***B2. Pictures***

A few high-resolution pictures of the Nymophone2 and the recordings are included in the “pictures” folder:

- Nymophone2.jpg
- Nymophone2 - Electronics housing.jpg
- Nymophone2 - Plate pickup.jpg
- Nymophone2 - Volume controls.jpg
- Recording setup.jpg
- Recording session.jpg

## ***B3. Video***

A demonstration video for the Nymophone2, and a video recording from the performance experiment is included in the “video” folder:

- |                               |  |
|-------------------------------|--|
| • Nymophone2 Presentation.mov | Presentation video for the Nymophone2. Some sound and control features are presented.  |
| • Nymophone2 Performance.mov  | Video recording of the solo improvisation of the third recording session presented in chapter 4. This video file is not part of the synchronized setup, and therefore not placed in the “Performance Experiment” folder. |

## ***B4. Performance Experiment***

Recorded files from the performance experiment presented in chapter four are included in the “performance experiment” folder. Please note, as remarked in chapter four, that the video in this folder need to be played back at 86% of normal speed to be synchronized with the other files. The audio and video files are synchronized to the SDIF file using the “sync” stream in the SDIF files, as presented in chapter four. Since I have only addressed the solo improvisation recording of the third recording session, I do only include the SDIF files containing GDIF data, the video and the audio recording for this recording.

- |  |  |
|--|--|
| • session3_recording1_impro-alone.aiff             | Audio file   |
| • session3_recording1_impro-alone.mov              | Video file   |
| • session3_recording1_impro-alone_raw.sdif         | SDIF file containing the raw GDIF layer                      |
| • session3_recording1_impro-alone_cooked.sdif      | SDIF file containing the cooked GDIF layer                   |
| • session3_recording1_impro-alone_descriptive.sdif | SDIF file containing the body and the functional GDIF layers |

## ***B5. Document***

This thesis is also available in PDF-format on the CD-ROM.